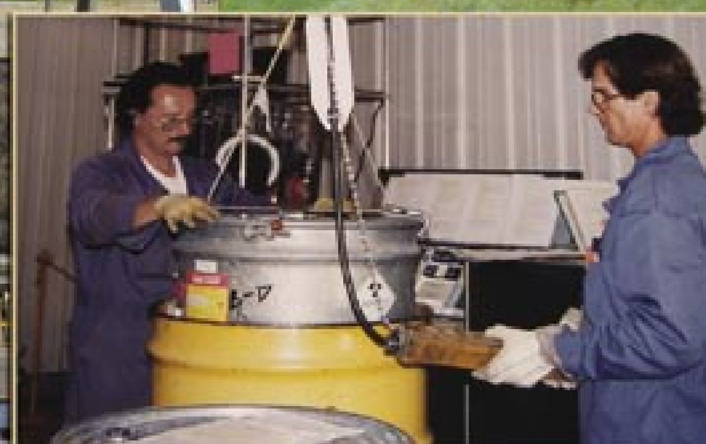
National Nuclear Security Administration

Lawrence Livermore National Laboratory

Recent Advances in the Environmental Protection Department

UCRL-BR-208053

December 2004



Lawrence Livermore National Laboratory
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For additional information, contact the
Environmental Protection Department:

Ellen Raber, Department Head
Lawrence Livermore National Laboratory
P.O. Box 808, L-626
Livermore, CA 94550
http://www.llnl.gov/epd/

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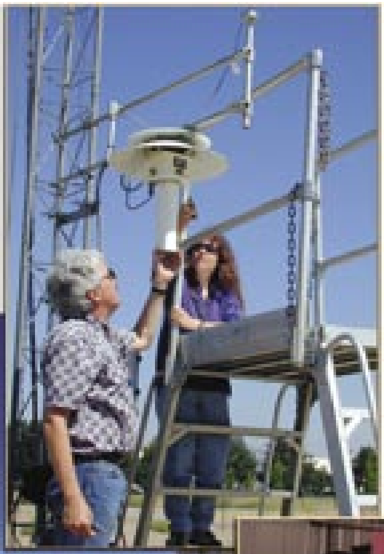
About the cover…

New instrumentation installed at the Livermore Site's 40-m meteorological tower aids in site-wide environmental monitoring for regulatory purposes, to support field activities and worker safety, and to monitor weather events. →



Drilling, testing, and evaluating underground characteristics are ongoing functions of the Environmental Protection Department. →

As part of LLNL's accelerated effort to dispose of its older (legacy) waste, characterization of head-space gas must be done on drums prior to offsite shipment. ↓

High-resolution, inductively coupled plasma, optical emission spectrometry is one of the analytical methods used to characterize metals in waste for proper disposition. →

More than 110 avian species have been documented at Site 300, including the Lazuli bunting, shown here, as part of the comprehensive Avian Monitoring Program.

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A BRIEF HISTORY OF LAWRENCE LIVERMORE NATIONAL LABORATORY

Lawrence Livermore National Laboratory (LLNL), a U.S. Department of Energy (DOE) facility operated by the University of California, serves as a national resource for science and engineering. The Laboratory's primary mission focuses on nuclear weapons and national security, including stockpile stewardship. Over the years, the mission has broadened to include areas such as strategic defense, energy, the environment, biomedicine, the economy, and science and mathematics education. This report reviews the Laboratory's environmental protection activities, capabilities, and recent technological highlights and discusses how the environmental protection work helps the Laboratory conduct its multifaceted mission.

LLNL is a full-service research laboratory with the infrastructure—engineering, maintenance, and waste management activities, as well as security, fire, and medical departments—necessary to support its operations and approximately 7,000 employees. LLNL works to ensure that its operations have a limited impact on the environment and that it complies with environmental laws as well as federal, state, and local regulatory guidelines.

LLNL operates two sites—the Livermore Site and Site 300. The Livermore Site occupies an area of 3.28 square kilometers on the eastern edge of Livermore, California. Site 300, LLNL's experimental testing site, is located 24 kilometers to the east in the Altamont Hills, and occupies an area of 30.3 square kilometers.

Bay Area locations of the Livermore, California Site and Site 300 of LLNL.

Because of post operations, both the Livermore Site and Site 300 are Superfund sites under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 and are undergoing remedial activities, including the Livermore Site Environmental Restoration Project and the Site 300 Environmental Restoration Project. Environmental monitoring activities are also conducted at both sites as well as in surrounding areas.

LLNL's Livermore Site.

Livermore Site Description and History

LLNL's Livermore, California site is located in southern Alameda County approximately three miles east of downtown Livermore. In the 1940s, the area now occupied by LLNL was the site of the Livermore Naval Air Station, operated by the U.S. Navy as a flight training base and an aircraft rework facility. At the base, volatile organic compounds (VOCs) were routinely used in aircraft and engine assembly, repair, overhaul operations, and paint stripping. Fuels, solvents, and other related materials were stored and disposed of on the site. Because of inadequate solvent disposal practices by the Navy, the groundwater underlying the site became contaminated with VOCs.

After the air station closed, interim users of the facilities were research and development organizations, including the California Research and Development Corporation (a subsidiary of

Standard Oil) and Pratt and Whitney. In 1954, LLNL (known then as the UC Radiation Laboratory) began storing and treating hazardous waste and organic solvents at the former air station. From 1956 to the present, LLNL's research and development activities involved the storage, use, and disposal of VOCs, fuel hydrocarbons, tritium, and other hazardous materials. Localized spills, landfills, surface impoundments, disposal pits, broken sewer pipes and lines, and leaking tanks compounded the original releases of hazardous materials.

During the 1970s, LLNL began eliminating emissions and discharges of hazardous materials. Today, all practices known to have contributed VOCs to the soil or groundwater have been discontinued.

In 1983, perchloroethylene (PCE) and trichloroethylene (TCE) were detected in offsite and onsite monitor wells. In response, the Laboratory initiated a thorough groundwater investigation. Under the requirements of the California Regional Water Quality Control Board, LLNL researchers drilled, logged, sampled, and hydraulically tested more than 350 monitor wells.

This investigation determined that a groundwater plume containing VOCs was migrating to the west-southwest from the site at a rate of approximately 100 ft per year. Three miles west of the groundwater plume containing VOCs are three municipal supply wells that feed a blended water system serving a population of more than 8,500 people, giving added urgency to the Laboratory's cleanup effort. As a result of groundwater treatment facilities that LLNL installed in the late 1980s and early 1990s, the offsite movement of contaminants has been curtailed.

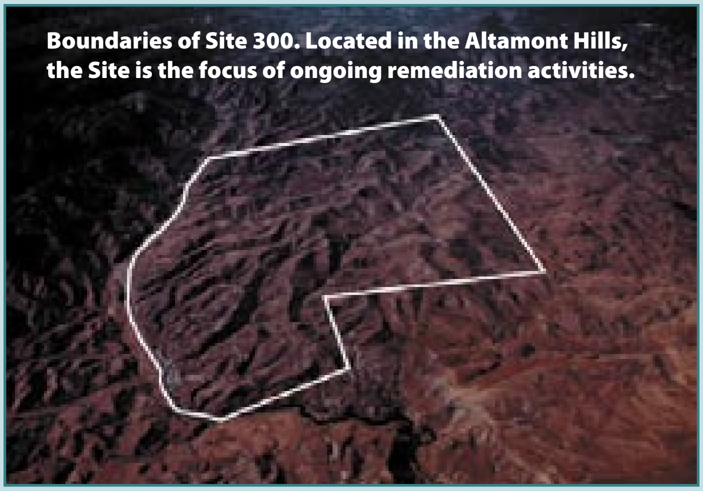
In 1987, the U.S. Environmental Protection Agency (EPA) added the Livermore Site to its National Priorities (Superfund) List. From 1990 to the present, many of our environmental activities at the Livermore Site have been directed at removing the contaminants from the groundwater and soil, preventing the release of pollutants and hazardous materials, and monitoring air emissions and wastewater discharges.

Site 300 Description and History

Site 300 is a 30.3-square-kilometer experimental test facility located on the sparsely populated, eastern slope of the Altamont Hills. It has been used since 1953 for testing nonnuclear, high-explosive compounds and for particle-beam research. More recently, the experimental test facility has also been used to develop and test environmental monitoring devices and innovative environmental remediation technologies. As a result of past processing, testing, and detonation of high-explosive materials, along with past waste management practices, some of the facility's soil and groundwater were contaminated.

In 1982, LLNL began investigating the soil and groundwater at Site 300. The investigation included reviewing past operations at the site, drilling, sampling and mapping the geology of monitor wells, sampling drinking-water wells on adjacent private property, sampling and analyzing site soils, and surveying the plant and animal life. In 1984, monitor wells revealed that the level of radioactive tritium exceeded California water quality standards in some areas of Site 300. By 1987, 10 locations within the site were found to have VOCs in soil, rock, and groundwater. In 1990, the EPA placed Site 300 on the National Priorities List and identified it as a site that required cleanup.

Today, our environmental restoration efforts at Site 300 include ongoing investigations, remediation, and advanced computer modeling, as well as the development and testing of innovative "green" environmental remediation technologies. Our objective is to clean up hazardous substances in soil and groundwater so thoroughly that we meet or exceed state and federal standards. Additional efforts include increased pollution prevention activities aimed at minimizing waste and emissions, as well as continued environmental monitoring to ensure compliance with existing state and federal regulations.



Boundaries of Site 300. Located in the Altamont Hills, the Site is the focus of ongoing remediation activities.

About the Environmental Protection Department

The Environmental Protection Department (EPD) is the lead organization for operational environmental support at Lawrence Livermore National Laboratory (LLNL). We are responsible for environmental monitoring, regulatory compliance, groundwater cleanup, environmental restoration, environmental consequence management, and radioactive and hazardous waste management.

LLNL's Environmental Policy

LLNL is committed to providing responsible stewardship of the environmental resources in its care. Science-based environmental stewardship is integrated into strategic planning and decision-making processes and into the management of work activities through the Integrated Safety Management System. In support of this policy, LLNL commits to:

- Continuously improve the efficient and effective performance of its environmental management system.
- Comply with applicable environmental laws and regulations.
- Incorporate pollution prevention, waste minimization, and resource conservation into planning and decision-making processes.
- Ensure that interactions with regulators, the Department of Energy (DOE), and the community are based on integrity, openness, and adherence to national security requirements.
- Establish appropriate environmental objectives and performance indicators to guide these efforts and measure progress.

EPD's Vision

Our vision is to develop and promote a robust, compliant, and innovative environmental program for the Laboratory. To achieve our vision, we use a variety of methods and tools to ensure regulatory compliance, effectively utilize the resources of the Laboratory that are available to us, and generate new funding and resources through existing DOE programs and Work for Others agreements. A key part of our vision is to establish a full partnership with all elements of LLNL so that we work together to meet the national laboratory mission and provide solutions to key local, regional, and national environmental problems.

One of our continuing challenges is to clean up past contamination at LLNL sites until those sites meet environmental standards. At the same time, we ensure that current Laboratory programs meet all applicable environmental regulations and do not adversely affect the surrounding environment, the community, and LLNL workers. Our program is responsible for instituting state-of-the-art environmental and waste management practices to ensure that LLNL continues to protect the environment in an effective and efficient manner that meets current needs and incorporates innovative advances in technology.

To meet the challenges, EPD continues to develop and share its expertise in the areas of pollution prevention, waste minimization and management, environmental restoration, and environmental monitoring. Our ultimate goals are to share our expertise regionally and nationally with government and industry, to contribute to the nationwide effort to clean up the environment, and to better manage our compliance with environmental regulations.

Environmental regulation is a complex and evolving issue because requirements frequently change, as do the policies and practices that are adopted within an organization to meet them. In response to the challenge, we have implemented a risk-based compliance approach to ensure that the intent of environmental laws and standards are always met.

Our Mission and Scope

The overall EPD mission is to support and contribute to the Laboratory's national security mission. This means championing environmental stewardship and addressing environmental regulatory, scientific, and technical issues that help the country with as much leverage as possible and that are appropriate for a national laboratory to undertake. As part of a broader national laboratory mission, we develop methods and implement technologies that allow for more effective waste treatment and decontamination, more cost-effective remediation and monitoring, better environmental monitoring techniques, and related achievements in the area of environmental protection. Key to our mission is an emphasis on providing good customer support to the institution and maintaining excellent working relations with our own regulatory agencies.

In support of the EPD mission, our department receives most of its direct funding from the DOE Environmental Restoration and Waste Management Programs, which provide about 65% of the department's budget. This funding supports the Livermore Site and Site 300 groundwater restoration Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) cleanup activities as well as the handling and disposition of LLNL's hazardous and radioactive wastes. About 5% of our current operating budget supports various projects for Work for Others sponsors. The remaining budget is provided by the Laboratory's indirect (overhead) funds. Key to our overall mission is:

- Assisting LLNL programs in understanding their environmental aspects and developing environmentally sound practices in day-to-day tasks. Such practices include:
  - Conducting environmental evaluations and addressing requirements under the National Environmental Policy Act (NEPA), California Environmental Quality Act (CEQA), the Endangered Species Act (ESA), and related federal and state requirements.
  - Providing employee environmental training and education to help identify and promote strategies to prevent or reduce air emissions, wastewater discharges, and hazardous wastes.

- Obtaining permits or exemptions for air, water, wastewater, and hazardous waste activities.
  - Developing and implementing pollution prevention and abatement strategies.
- Ensuring environmental compliance through monitoring, risk assessment, analysis, and emergency response actions for LLNL sites. Evaluating the impact of ongoing LLNL operations on the surrounding environment by sample collection, analysis, data reduction, and simulation modeling methods for water and air.
- Developing and conducting cost-effective environmental restoration and remediation, primarily to support the ongoing CERCLA cleanup activities at our two sites.
- Designing and applying appropriate, cost-effective treatment technologies to manage radioactive, hazardous, and mixed waste streams. As part of this effort, LLNL maintains and operates several Resource Conservation and Recovery Act (RCRA)-permitted nuclear facilities.
- Decommissioning and disposition of radiological, nuclear, and nonnuclear facilities in support of infrastructure improvements.
- Supporting the national mission for homeland security environmental monitoring and restoration.

Another part of our mission is expanding support to the DOE and other federal and state agencies through Work for Others agreements where we have unique technical expertise. Examples include helping the Department of Homeland Security (DHS), the University of California (UC), the California Department of Toxic Substances Control (DTSC), the California State Environmental Protection Agency (Cal/EPA), the U.S. Environmental Protection Agency (EPA), the Nuclear Regulatory Commission (NRC), the U.S. Department of Defense (DOD), and other state and federal agencies on environmental issues. We are also working with Russia and other former Soviet states through the State Department's International Science and Technology Center (ISTC) Program, and with first-line responders on various hazardous materials issues related to decontamination and restoration in support of homeland security.

To carry out the EPD mission, we have developed an integrated, multidisciplinary, risk-based evaluation approach to ensure that the intent of environmental laws and standards are met. By combining expertise in the scientific, engineering, technical, and management fields, we provide a comprehensive, balanced range of resources and disciplines to address environmental issues, identify best management practices, solve environmental problems, and prevent further environmental damage. Our experts provide quality assurance and environmental education, ensure regulatory compliance, and facilitate community relations and public participation. The EPD also joins with other national laboratories, LLNL programs, the UC, and the private sector to work on environmental projects.

The EPD relies on commercial laboratories to generate a large percentage of the analytical data that are the basis for many decisions. Such data are used for performance monitoring of various environmental waste-management, restoration, and permitting activities in support of LLNL programs. The EPD Quality Assurance Program was part of the initial development of the DOE Consolidated Auditing program (DOECAP), which is the vendor-qualification process used to approve commercial analytical laboratories for use. We serve as a voting member of the DOECAP Steering Committee and function as qualified lead auditors.

The EPD consists of three divisions and several department-level activities, which are identified in Table 1. Each division has a uniquely defined role in the Laboratory's pursuit of environmental achievement and compliance. In the pages that follow, we introduce the divisions and programs of EPD and highlight their recent innovations in environmental technology. Their overall contributions to a cleaner environment by topic are highlighted starting on page 1.

Table 1. Department-level activities and three divisions of the Environmental Protection Department.

Environmental Protection Department		
Departmental-Level Activities		
• Institutional Environmental Training • Environmental Emergency Management	• Environmental Assurance • Decommissioning and Demolition Programs	
EPD Divisions		
Environmental Restoration Division (See page 1)	**Radioactive and Hazardous Waste Management Division (See page 15)**	**Operations and Regulatory Affairs Division (See page 27)**
Environmental Engineering Hydrogeology Environmental Chemistry and Biology Information Systems and Management -------------------------------- Livermore Restoration Project Site 300 Restoration Project	Nuclear Facilities, Safety, and Compliance Information Management Storage and Disposal Waste Generator Services Waste Treatment ------------------------------ Legacy Waste Program	ChemTrack and Technical Services Environmental Evaluations Environmental Operations Permits and Regulatory Affairs Terrestrial and Atmospheric Monitoring and Modeling Water Guidance and Monitoring

Environmental Restoration Division

Introduction

The Environmental Restoration Division (ERD) was formed to protect public health and the environment by investigating and remediating contamination of soil and groundwater from past operations at LLNL's Livermore Site and Site 300. To accomplish its mission, ERD develops and applies innovative, state-of-the-art approaches to restore the environment, and in so doing, serves as a resource in the field of environmental restoration technology. ERD's responsibilities include:

- Ensuring compliance with environmental regulations and DOE requirements as applied to site-wide groundwater contamination and the cleanup of groundwater at both the Livermore Site and Site 300.
- Advancing state-of-the-art contaminant hydrogeology and restoring groundwater and soils.
- Providing and managing a series of well-characterized and instrumented test beds to assist in developing remediation technologies.
- Collaborating with others in the research, development, demonstration, testing, and evaluation of environmental restoration technologies.

For further information, contact Jesse Yow (yow1@llnl.gov).

Technology Highlights

Engineered Plume Collapse Using Hydrostratigraphic Analysis

We have developed a strategy called engineered plume collapse (EPC) to accelerate cleanup of the more than 38 groundwater plumes identified at the Livermore Site. The strategy accelerates cleanup over and above what would be accomplished under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) Record of Decision cleanup plan. EPC is an integrated, multidisciplinary remediation strategy that reduces the cost of site cleanup by: (1) controlling further plume migration with source control wells; (2) rapidly decreasing volatile organic compounds (VOCs) in the distal and mid-range portions of individual plumes, thereby collapsing the plumes back to their source areas; (3) focusing on source area cleanup using advanced technologies; and (4) achieving relatively early site closure.

Key to the success of EPC is a thorough understanding of the hydrogeologic factors that control the site-specific flow and transport of contaminants in subsurface soils. At ERD, we have developed a methodology called hydrostratigraphic analysis to divide the sediments beneath LLNL into hydrostratigraphic units (HSUs) based on a detailed analysis of chemical, geological, geophysical, and aquifer test data. Hydrostratigraphic analysis has enabled us to integrate large, complex data sets into a detailed three-dimensional model of the subsurface based on measured hydrogeological properties.

Through hydrostratigraphic analysis, we are enhancing our ability to manage and prioritize groundwater cleanup, improving our ability to identify and target contaminant migration pathways, delineating individual plume geometries, identifying the relation between plumes and source areas, and better defining the hydraulic capture areas associated with our extraction wells. With a comprehensive understanding of LLNL subsurface conditions, we are effectively implementing the EPC strategy, improving cleanup time, and reducing overall project costs. Through hydrostratigraphic analysis, LLNL is minimizing the number of wells needed for site cleanup and compliance monitoring and, in turn, is reducing expenditures for wells and pipelines.

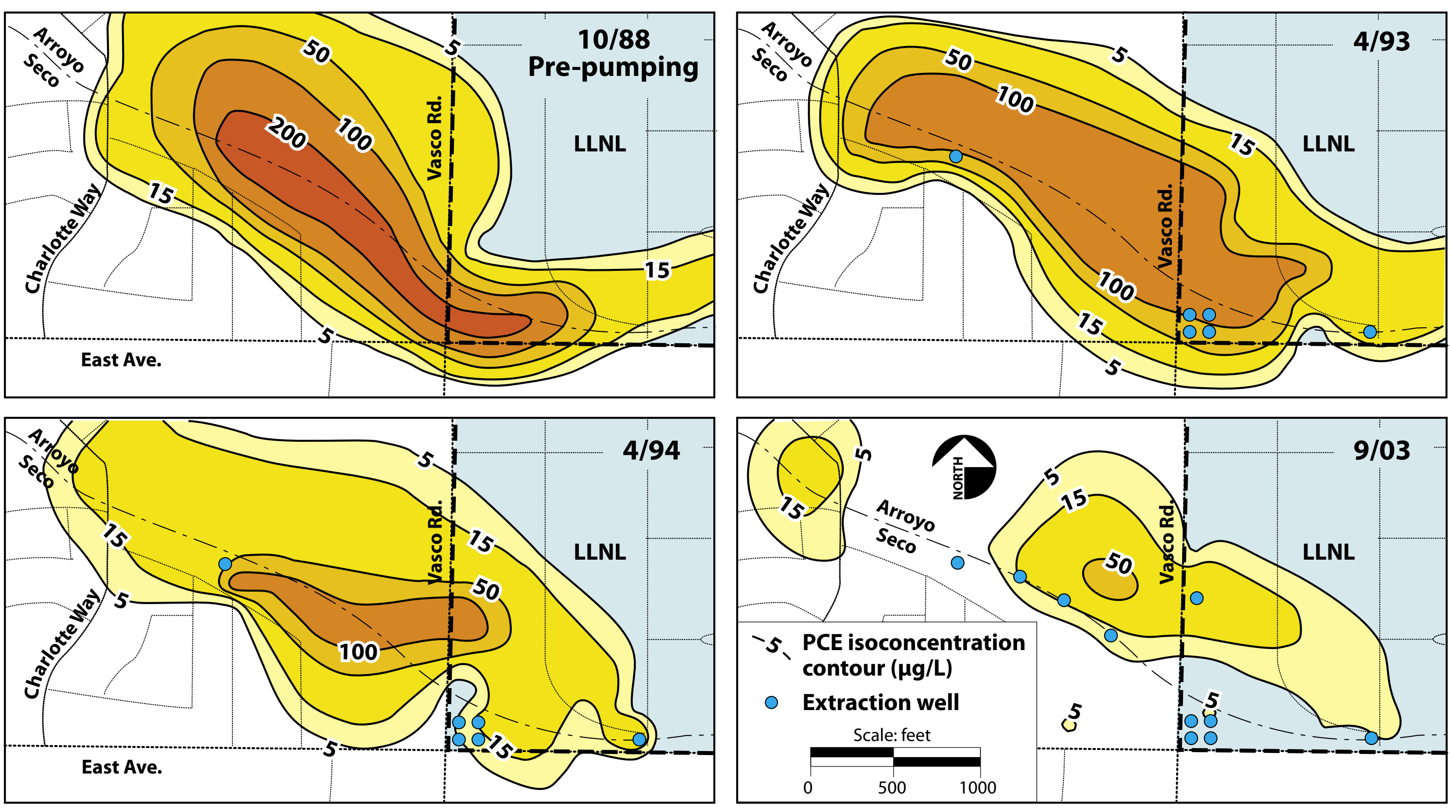
HSU methodology is also allowing cleanup to progress faster than expected because ERD staff now have the information required to place extraction wells for maximum effectiveness. Figure 1 is a sequence of maps from October 1988 to September 2003 showing steady progress of LLNL's groundwater cleanup of the contaminated HSU-2 water-bearing zone. Together, the maps show a dramatic decrease in VOC concentrations in this HSU, illustrating the capacity of hydrostratigraphic analysis to effectively monitor plume changes as remediation work proceeds. Over the last 15 years, perchloroethylene (PCE) concentrations in this HSU along the western margin of the site have been reduced from more than 1,000 parts per billion to less than 30 parts per billion. The newly installed extraction wells and associated pipelines that were designed using the HSU methodology may allow cleanup objectives to be reached in another 25 years rather than the Laboratory's original estimate of 50 years.

Hydrostratigraphic analysis has also proven to be an effective visualization tool for presenting complex geologic and groundwater remediation issues to the DOE, federal and state regulatory agencies, and the local community. In addition, hydrostratigraphic analysis forms the basis of two-and three-dimensional computer simulations of groundwater contaminant transport. The simulations use advanced physics codes to estimate cleanup times, costs, and design parameters. Finally, it is proving to be a valuable method to evaluate the effectiveness of innovative cleanup technologies that may be needed to achieve early site closure.

The philosophy behind the currently used EPC remediation strategy is that smart pump-and-treat, combined with other existing technologies and new methodologies, such a hydrostratigraphic analysis, can be demonstrated to be time- and cost-effective in removing VOCs from distal plumes and source areas that otherwise would continue to contaminate groundwater. This strategy applies proven, smart, pump-and-treat technology to effectively remediate high-permeability zones, and it is being combined with dual-phase extraction (simultaneous soil vapor and groundwater extraction with or without hot air injection) that shows great promise in effectively remediating low-permeability zones, where fine-grained materials are highly contaminated.

For further information, contact Fred Hoffman (hoffman4@llnl.gov)

Figure 1. Perchloroethylene (PCE) isoconcentration contours in HSU-2 from 1988 to 2003.



Monitored Natural Attenuation

Monitored natural attenuation (MNA) refers to a reliance on natural physical, chemical, or biological processes to reduce subsurface contaminant mass, concentration, toxicity, or mobility and achieve site-specific water quality objectives in a reasonable time. The *in situ* processes include intrinsic biotransformation and biodegradation, sorption, volatilization, dilution, dispersion, and radioactive decay. MNA can be implemented at some sites as the sole remedy for groundwater cleanup. At many other sites, it is used along with active measures, such as contaminant source removal or pump-and-treat technology. Responsible parties and regulators rely more and more on natural attenuation where acceptable as a strategy for cost-effective groundwater cleanup.

MNA can be demonstrated as an acceptable remedial strategy through several lines of evidence. According to the EPA Office of Solid Waste and Emergency Response, regulatory acceptance for MNA can be gained by establishing that:

- Contaminants do not pose an unacceptable human health risk.
- Source areas are controlled or eliminated.
- Plume contours are static or collapsing.

The burden of proof is on the responsible party to present technically defensible, site-specific evidence that natural attenuation processes will satisfy the three criteria in a reasonable time. An interdisciplinary team of Environmental Restoration Division scientists, in collaboration with scientists from other directorates, such as Chemistry and Materials Science (C&MS), have been evaluating sites using state-of-the-art analytical methods—including stable isotope analysis, liquid chromatography/mass spectrometry, DNA "fingerprinting," and reactive transport modeling—to determine whether contaminants are attenuating naturally. Methods we have recently developed to document the intrinsic biodegradation of gasoline hydrocarbons in aquifers are described in the article, "Evidence That Bacteria Can Clean Up Aquifers," later in this publication. Those methods rely on the emerging technologies of near-real-time, quantitative, polymerase chain reaction (PCR) analysis to detect specific genes, and isotope dilution liquid chromatography/tandem mass spectrometry to detect specific metabolites.

To date, we have gained regulatory approval for MNA remedies at Pit 6 (for VOCs) and at the Building 850 Firing Table (for tritium), both located at Site 300 (Fig. 2). The EPA has agreed to consider an MNA remedy for nitrate in the High-Explosives (HE) Process Area, where it has been demonstrated that nitrate is naturally attenuating in groundwater. As a result, we are seeing substantial reductions in groundwater cleanup costs.

For further information, contact Vic Madrid (madrid2@llnl.gov).

The Problem of Nitrate. Nitrate is a natural and anthropogenic constituent of groundwater. At Site 300, nitrate ranges in concentration from levels less than the analytical detection limit of 0.4 mg/L to greater than 45 mg/L, which is the maximum contaminant level (MCL) set by the EPA. The processing, formulation, and machining of HE chemicals at Site 300 during the 1960s and 1970s released several chemicals, including nitrate, to the groundwater. In collaboration with C&MS researchers, we conducted an interdisciplinary study of processes that influence the spatial and temporal distribution of nitrate in a bedrock aquifer located beneath the HE Process Area at Site 300. This study was undertaken to evaluate the fate of nitrate in groundwater and determine whether it poses an unacceptable risk to offsite receptors located downgradient of the site.

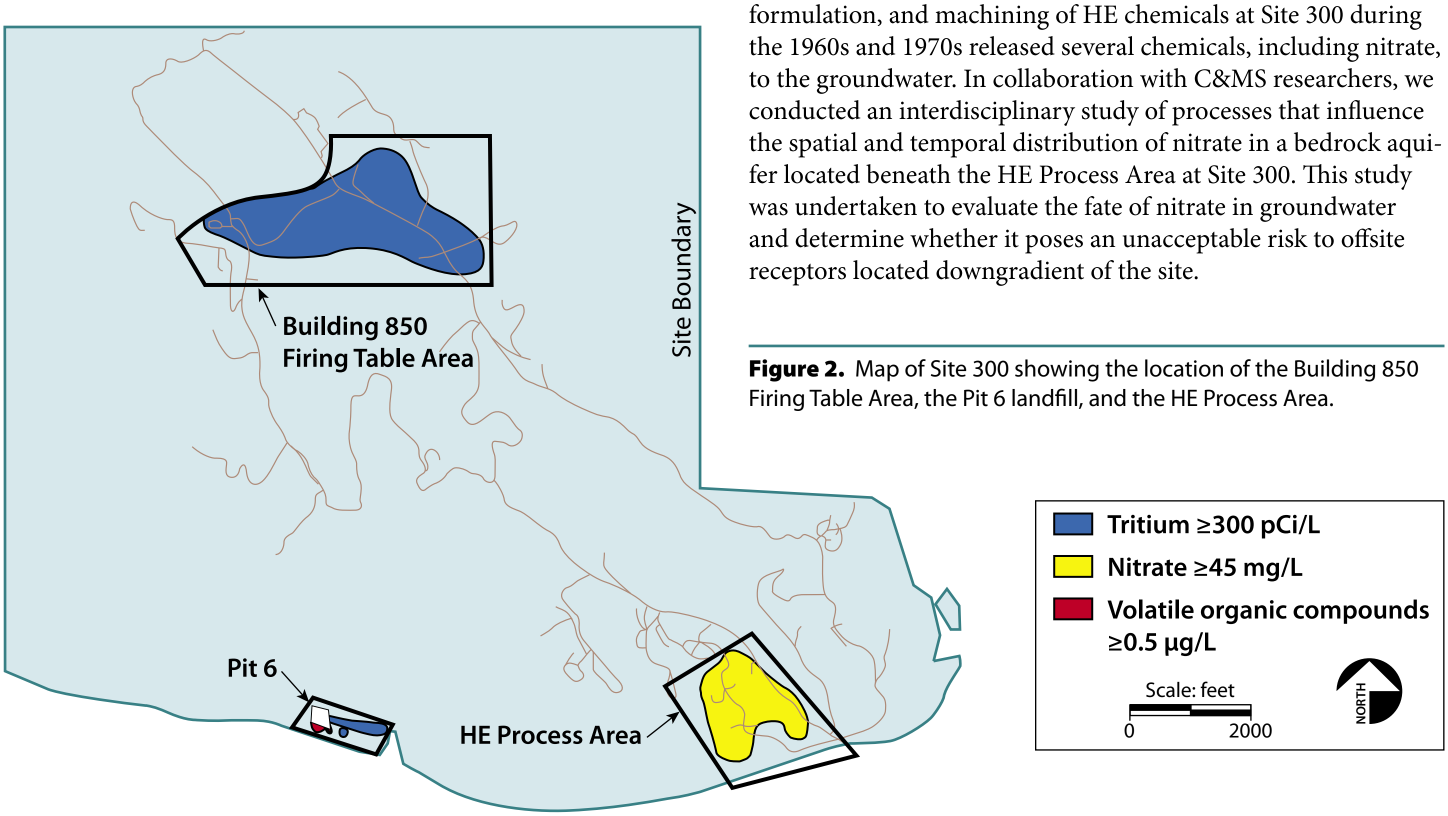


Figure 2. Map of Site 300 showing the location of the Building 850 Firing Table Area, the Pit 6 landfill, and the HE Process Area.

Denitrification is the microbial transformation of nitrate to harmless nitrogen gas, a process that only occurs in the absence of dissolved oxygen. Several lines of evidence strongly suggest that microbial denitrification is naturally attenuating nitrate in this aquifer:

- Both nitrate and dissolved oxygen concentrations in groundwater decrease dramatically as groundwater flows from unconfined to confined aquifer conditions.
- Stable isotope signatures of nitrogen and oxygen in dissolved nitrate indicate a trend of isotopic enrichment that is characteristic of denitrification.
- Dissolved nitrogen gas, the product of denitrification, is highly elevated in nitrate-depleted groundwater in the confined region of this aquifer.

Our study concluded that chemolithoautotrophic denitrification, with the mineral pyrite as the electron donor, is the most plausible process responsible for nitrate attenuation in this aquifer. Our conclusion is based on:

- Low dissolved organic carbon concentrations (<1.5 mg/L) that could not support heterotrophic denitrification.
- The common occurrence of disseminated pyrite in the aquifer.
- The trend of increasing sulfate (a product of pyrite oxidation coupled with denitrification) as groundwater flows from aerobic and unconfined to anoxic and confined aquifer conditions.

Long-term groundwater monitoring data indicate that nitrate concentrations are relatively high and constant in the aquifer's recharge area, typically ranging from 70 to 100 mg/L of nitrate as NO_3^-. These concentrations decrease rapidly to levels less than the analytical detection limit of 0.4 mg/L in the downgradient confined region of the aquifer, suggesting a balance between rates of nitrate loading and removal by denitrification. Because the natural attenuation of nitrate occurs within Site 300 boundaries, groundwater migrating offsite is devoid of detectable nitrate. The result is that any risk to downgradient receptors is eliminated, and regulatory acceptance criteria for MNA are satisfied. The regulatory agencies have agreed to consider an MNA remedy for nitrate in this aquifer. If accepted, the MNA remedy would result in greatly reduced groundwater cleanup costs.

For further information, contact Harry Beller (beller2@llnl.gov).

Tritium. Open-air testing of weapons components during the 1960s and 1970s resulted in releases of tritium to groundwater at Site 300. Tritiated water poses a particular challenge for the DOE Environmental Restoration Program because there are currently no cost-effective, small- or medium-scale technologies available to treat tritiated water. In 2001, an Interim Record of Decision (ROD) for the remediation of Site 300 was signed by the DOE along with state and federal regulatory agencies. The Interim ROD included MNA as a remedy for the tritium groundwater plume emanating from the most active firing table at Site 300, the Building 850 Firing Table. This is one of the first RODs in the DOE complex that includes an MNA remedy.

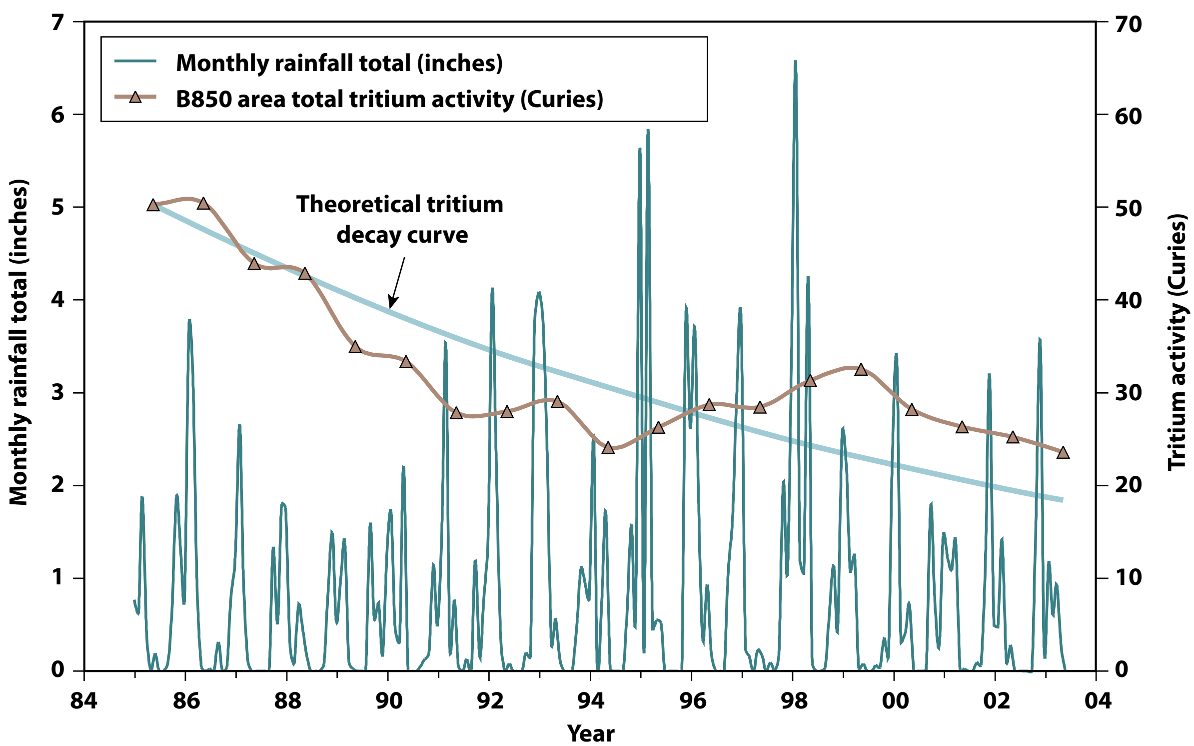


Figure 3. Tritium activity plots for the Building 850 tritium plume from 1985 to mid-2003.

Evidence supporting natural attenuation for tritium at this site is based on hydrogeologic analysis of groundwater monitoring data collected since 1985. The analysis indicates that the maximum tritium activity in Building 850 groundwater decreased from more than 500,000 pCi/L to less than 100,000 pCi/L between 1985 and 2002. Furthermore, volumetric analysis from water-level and tritium-activity data indicates that the total tritium activity in the plume decreased by one half, from 51 to 25 Curies, during the same period (Fig. 3). The decrease in total activity is mainly from radioactive decay because the half life for tritium is 12.3 years. Annual time-series tritium plume maps indicate that, although the areal extent of detectable tritium has increased over time, the extent of tritium greater than the 20,000-pCi/L MCL has decreased (Fig. 4). Our analysis predicts that tritium activities within the plume will decay to less than the MCL between 2015 and 2040.

We will also propose an MNA remedy for tritium in groundwater emanating from several Site 300 landfills, with the caveat that further releases of tritium will be minimized or eliminated by engineering controls. The engineering controls may include an hydraulic diversion system to redirect surface and shallow groundwater away from landfill pits during heavy rainfalls, thereby minimizing or preventing groundwater from entering the landfills and mobilizing additional tritium.

For further information, contact Michael Taffet (taffet1@llnl.gov).

Evidence That Bacteria Can Clean Up Aquifers

Groundwater contamination from leaking underground fuel tanks (LUFTs) is a pervasive problem at federal and commercial facilities throughout the U.S. More than 427,000 releases from LUFTs have been confirmed nationwide, and the cleanup backlog totals more than 142,000 sites according to recent EPA figures. Among the compounds in gasoline that are of greatest concern are benzene, toluene, ethylbenzene, and the three xylene isomers (known collectively by the acronym BTEX). BTEX are among the most toxic and water-soluble constituents of gasoline.

Bioremediation can be a cost-effective method to restore BTEX-contaminated aquifers to satisfactory conditions. Intrinsic bioremediation, also called natural attenuation, relies on indigenous bacteria to degrade contaminants in place. Although LUFT owners who are responsible for cleanup favor such an approach, regulators and the public sometimes view intrinsic bioremediation as a do-nothing approach. To address such concerns at a specific site, it is necessary to demonstrate in a scientifically credible manner that biodegradation is actually occurring, rather than nondestructive processes that might appear to be decreasing concentrations, such as dilution or dispersion.

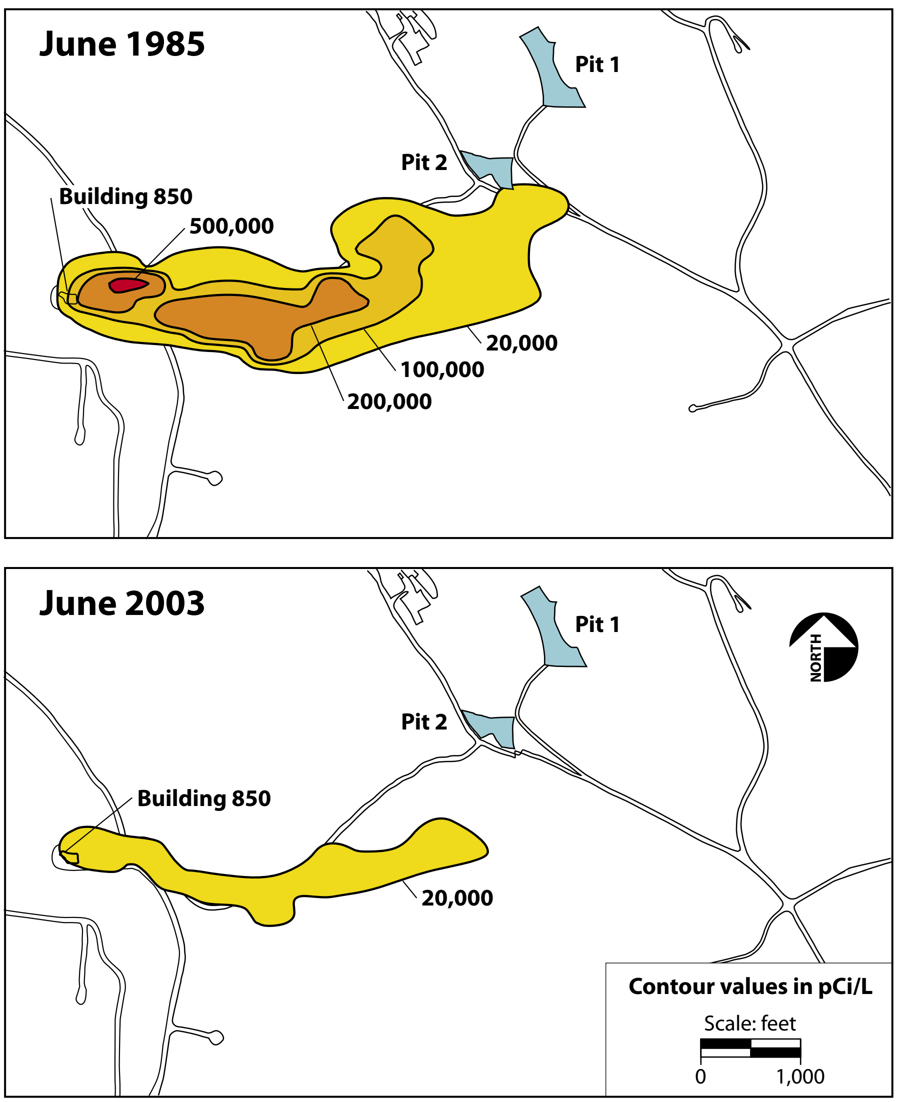


Figure 4. Plume maps of the Building 850 tritium plume. Results show a decrease in the extent of tritium concentration greater than 20,000 pCi/L between 1985 and 2003.

Groundwater at LUFT sites is typically oxygen depleted (anaerobic) because oxygen-respiring (aerobic) bacteria use up the available oxygen. Only 15 years ago, conventional wisdom held that anaerobic BTEX-degrading bacteria did not exist. Today, we not only know that such bacteria exist, but we also know the key enzyme (benzylsuccinate synthase or BSS) that carries out the first step of anaerobic degradation of toluene and xylenes (Fig. 5). In addition, we have elucidated the gene sequences that code for this enzyme in some bacteria.

Environmental Restoration Division researchers are using two techniques to rapidly and reliably detect the bacterial degradation of toxic compounds in soil and groundwater samples from LUFT sites. The techniques are the real-time polymerase chain reaction (PCR) and isotope-dilution liquid chromatography/tandem mass spectrometry (LC/MS/MS; see Fig. 6).

The real-time PCR approach focuses on the bssA gene for counting aquifer bacteria that are associated with anaerobic toluene and xylene degradation. Each bacterial cell typically contains only one copy of the bssA gene, so the number of gene copies in a given sample is equivalent to the population of bacteria that contain bssA. If anaerobic bacteria at a LUFT site are metabolizing BTEX and proliferating, we would expect populations to be greater in BTEX-contaminated areas than in nearby uncontaminated areas. Such information allows us to compare bacterial populations containing bssA over distance or time.

Real-time PCR provides a way to quantify copies of the bssA gene by targeting DNA sequences that are unique to this gene. Our research team first studied the degree of similarity in the bssA gene sequence among different toluene-degrading bacterial strains. We then focused on a stretch of DNA—about 130 base pairs—to develop our real-time PCR method. Our studies focused on microcosms made with aquifer sediments from four sites with different histories of BTEX exposure, including three LUFT sites and an uncontaminated site. We spiked the sediments with BTEX, incubated them anaerobically in the laboratory, and monitored BTEX degradation activity. Real-time PCR analysis of DNA extracted from the microcosms revealed that bacterial population trends were consistent with observed anaerobic toluene degradation activity. In samples with the most rapid toluene degradation, the numbers of bssA copies increased 100- to 1,000-fold during the first 4 days of incubation, the time when most of the toluene was being consumed. Real-time PCR has many advantages over other bacteria-counting methods that require cultivating bacteria and then calculating the original populations. Cultivating anaerobic bacteria can be quite difficult and is time-consuming, whereas the real-time PCR method is complete in less than an hour. PCR also detects as few as five copies of a gene per analysis and is highly selective, thereby avoiding false-positive results.

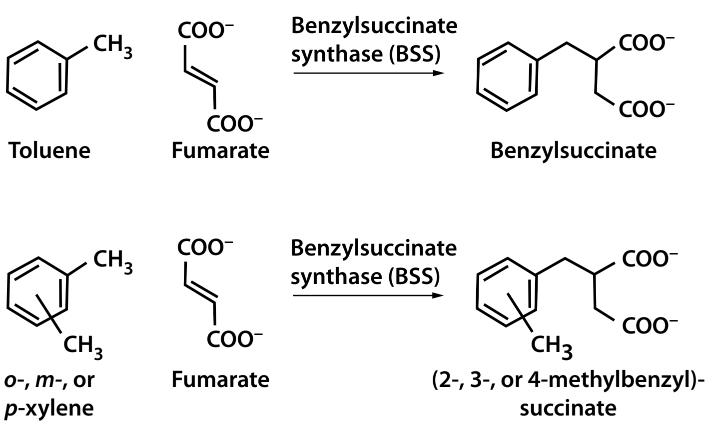


Figure 5. Anaerobic bacteria use the BSS reaction to attack (a) toluene and (b) xylenes in the first step of the biodegradation process. The BSS enzyme catalyzes the addition of toluene to fumarate, a compound typically present in many bacteria.

Our second approach for tracking intrinsic bioremediation of BTEX in groundwater sensitively detects the unique metabolic products of the BSS reaction using isotope-dilution LC/MS/MS. The target metabolic products are benzylsuccinate and methylbenzylsuccinate isomers, which are uniquely associated with anaerobic toluene and xylene degradation, respectively. When found in groundwater, these "signature" metabolites are definitive indicators of anaerobic bacteria degrading hydrocarbons *in situ*. Traditional analytical methods to detect these metabolites are both labor-intensive and time-consuming,

Figure 6. An ERD researcher works with the liquid chromatograph/tandem mass spectrometer.

in that they require extraction, concentration, and derivatization steps. Isotope-dilution LC/MS/MS precludes the need for those steps, takes less than 10 minutes, is highly sensitive and precise, and requires less than 1 milliliter of groundwater. Our research team analyzed groundwater samples collected quarterly for a year from 12 wells at a fuel terminal known to have contaminated groundwater. Methylbenzylsuccinates were detected in the three wells with the highest BTEX concentrations (methylbenzylsuccinate concentrations ranged from less than 0.3 to 205 micrograms per liter). Results showed a strong and consistent correspondence between concentrations of methylbenzlysuccinates and their parent compounds (xylenes) throughout the most contaminated portion of the aquifer.

Several challenges remain to be addressed. The first is to move from qualitative evidence that biodegradation is occurring to quantitative evidence showing the rate of *in situ* biodegradation. Another long-term goal is to better understand how ethanol (which is a strong contender to replace MTBE in gasoline) could affect populations of anaerobic BTEX-degrading bacteria. We are also extending the application of our techniques to other classes of contaminants, such as nitrate and high explosives.

For further information, contact Harry Beller (beller2@llnl.gov) or Staci Kane (kane11@llnl.gov).

Age of Groundwater as an Indicator of Vulnerability to Contamination

The source of half of California's drinking water is groundwater. Because of contamination identified at several California public drinking water wells, the state mandated the Groundwater Ambient Monitoring and Assessment (GAMA) program in 1999 to investigate the extent to which groundwater is susceptible to contamination. The program, funded by Cal EPA, involves testing each of the roughly 16,000 public drinking-water wells located throughout California.

LLNL is a logical choice for tackling this daunting task because the Lab has a history of working with the state on groundwater issues and providing solutions. The Environmental Protection Department was part of an investigation that assessed leaking underground fuel tanks (LUFTs) around California and their effects on the state's groundwater. For Cal EPA, Laboratory scientists developed GeoTracker, which is a geographic information system that provides online assess to environmental and regulatory data on more than 15,000 LUFT sites and all public well sites in California.

The initial structure of GeoTracker included an Internet shell that allowed easy access to LUFT sites and drinking water receptors in a geographical context. At first, the data had low accuracy, but the GeoTracker interface was designed to allow owners of the sites (regulator s and water agencies) to interactively update the locations and accuracy of data. Assembly Bill 2886, introduced in 2000, now requires that raw LUFT environmental data, such as groundwater levels and chemistry, be submitted by Responsible Party consultants. Groundwater chemistry must be submitted electronically over the Internet in a relational database founded on the Electronic Data Format (EDF), whose structure is public domain and has had developmental input from analytical laboratories. Over time, AB2886 requires that all other contaminated groundwater sites in California must follow suit, including the LLNL and Site 300 Superfund sites. So far, data submission has been a great success, with more than 50,000 submissions of electronic data. GeoTracker will serve as a repository for the data generated by the GAMA program.

LLNL scientists have partnered with the California State Water Resources Control Board and U.S. Geological Survey to test 1,200 wells to date, analyzing wells in the Los Angeles–Orange County basin, the Santa Clara Valley, the Livermore–Niles area, and the counties of Sacramento, Butte, Fresno, and San Joaquin. We are determining where contamination has occurred, groundwater flow patterns, and where the groundwater originates. Because the age of water is a good indicator of its probability of contamination, the work begins with age dating water from municipal drinking water wells. In essence, water that has been in the subsurface for more than 50 years is relatively isolated from surface pollutants, whereas younger water may have more recent contact with ground surfaces where contaminants are present.

The tritium–helium-3 method, which is available at only a handful of laboratories, including LLNL, can be used to determine how long water has remained out of contact with the atmosphere. Rainfall contains tritium, which has a half-life of 12.3 years. It decays to helium-3, which is a stable noble gas that remains in solution once water containing tritium enters the aquifer. As tritium continues to decay over time, the amount of helium-3 increases, and the amount of tritium decreases, whereas the sum of both remains constant. By measuring both amounts, we can determine when water entered the aquifer. Noble-gas mass spectrometry allows measurements sensitive to only a few thousand helium-3 atoms. Such sensitivity means we can determine the age of a water sample to within about one year.

We are applying other analytic techniques to test the principle that younger water is more contaminated than older water, and to obtain a larger picture of groundwater resources in the state. For example, gas chromatography, when combined with mass spectrometry to track VOCs, can detect contamination at ultra-trace levels. Such compounds are found nearly everywhere on Earth at low concentrations. The detection results indicate whether a component of sampled groundwater has been in recent contact with the surface and augment the age-dating results. Another technique involves measuring the ratio of two stable oxygen isotopes (oxygen-16 to oxygen-18). This ratio depends on where water precipitated, the elevation at which it was found (Fig. 7), and the distance from the ocean. With an isotope-ratio mass spectrometer, we can thus determine the geographical source of water in a sample.

Analysis of our data to date suggests that older water can remain relatively contaminant free despite the proximity of a well to contaminating activities. For example, drinking water aquifers in the Silicon Valley have remarkably uncontaminated water even though Santa Clara County has more Superfund

Figure 7. The pattern of oxygen isotope ratio shows the influence of American River recharge on wells between the American River and Highway 80 in Sacramento, CA. A lighter oxygen isotope signature is observed in the rivers draining the Sierra Nevada Mountains because the water is derived at a colder temperature (higher elevation). Local precipitation in the Sacramento area results in a δ18O value that averages approximately −7.5%.

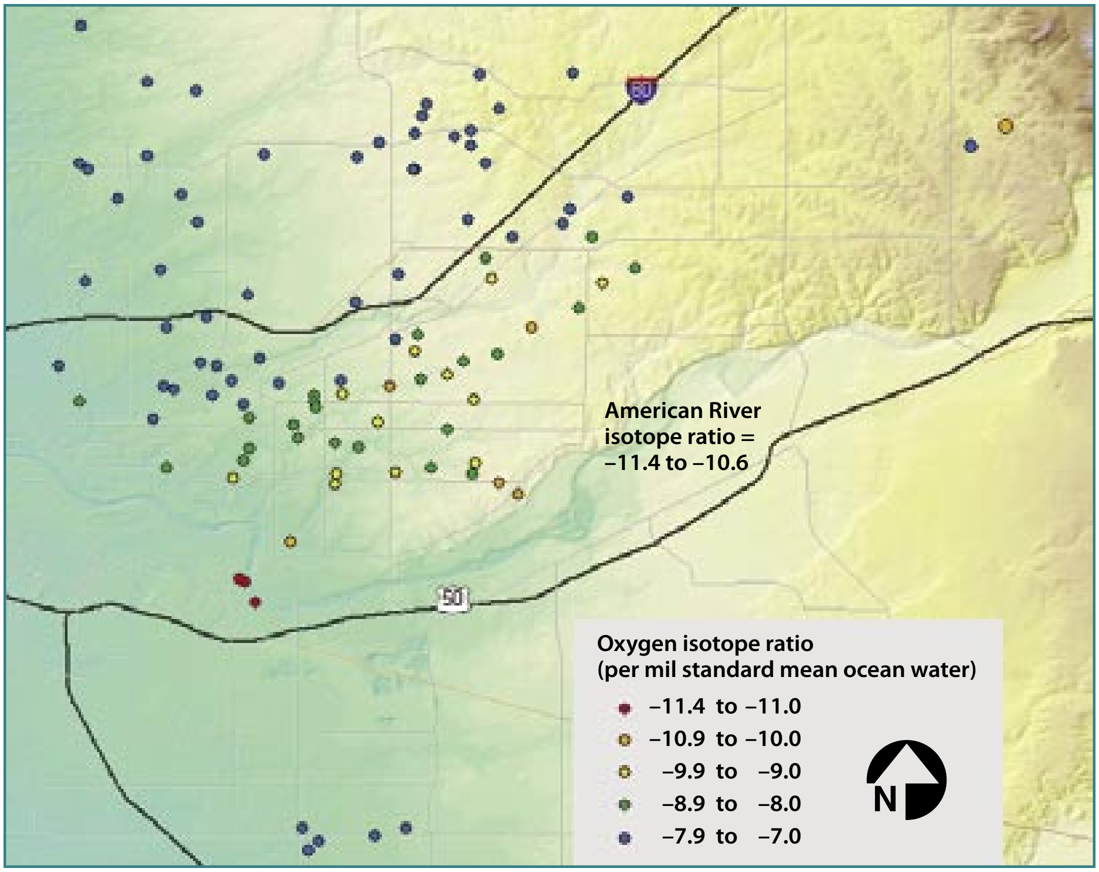
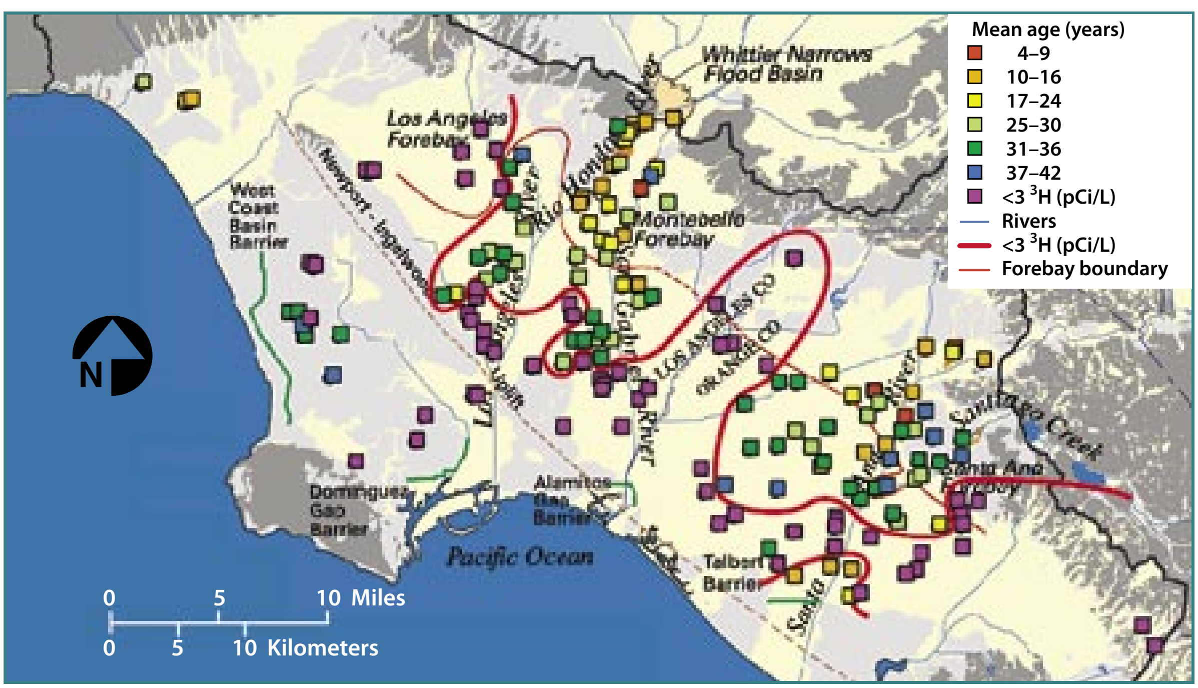


Figure 8. In Southern California, young groundwater near recharge areas has greater susceptibility to contamination than older groundwater.



sites than any other county in the nation. Most of this water has been resident in underground aquifers longer than the contaminants have been present. Similar results are seen in the Los Angeles and Orange County basins (Fig. 8). There, vertical transport of water into the aquifer is blocked by thick layers of clay. In contrast, results from the Livermore Valley show somewhat greater vulnerability of younger water to contamination because of the absence of such pervasive clay layers.

Our future work will focus on studying nitrate contamination, which is a frequent cause for shutting down drinking water wells in California. In the meantime, our age-dating work is helping California officials to make informed decisions about protecting drinking water wells and planning future development.

For further information, contact Jean Moran (moran10@llnl.gov) or Brendan Dooher (dooher1@llnl.gov).

Portable Treatment Units

Groundwater cleanup has traditionally relied on large, permanent treatment facilities that can be relatively expensive to build and operate. We have developed portable treatment units (PTUs) that are smaller, reliable, easy to use, modular, and more economical. Our units clean up contaminated groundwater efficiently, increase the flexibility of cleanup, and reduce both capital and operational costs. Four types of PTUs are now in use at LLNL's Livermore Site and Site 300. They are solar-powered treatment units (STUs), miniature treatment units (MTUs), containerized treatment units, (CTUs), and granular activated-carbon treatment units (GTUs). Each type can be easily relocated with a forklift.

As shown in Fig. 9, selection of a particular type of treatment unit is determined by specific conditions at a site, primarily groundwater flow rate and the concentration of contaminant. We can deploy multiple units when large flow rates need to be handled. A modular approach can address specific contamination issues. PTUs are being used to combine air stripping, granular activated carbon, ion exchange, biological, and other treatments. After a given location is cleaned up, a PTU is relocated rather than becoming surplus. After deploying the PTUs, capital costs were reduced by 57% compared to conventional, fixed-treatment facilities with pipelines for the Livermore Site.

For further information, contact Ed Folsom (folsom1@llnl.gov).

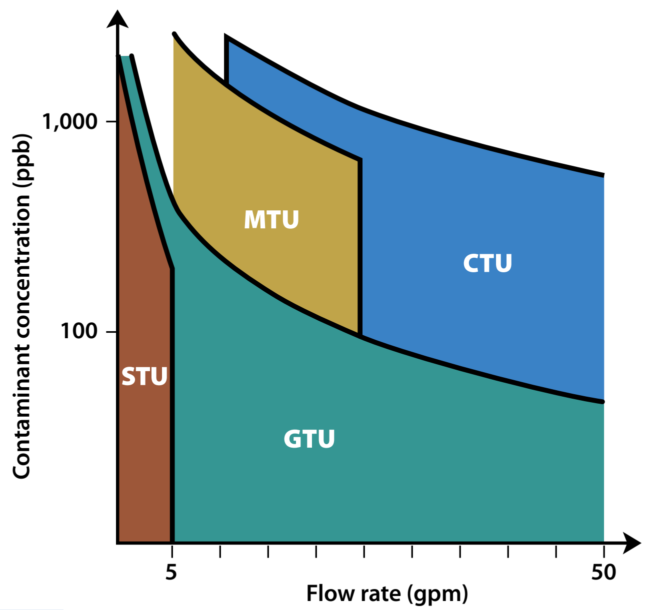


Figure 9. Four different kinds of PTUs are tailored to groundwater flow rate and other factors. For example, an STU treats groundwater flows up to about 5 gallons per minute and can be located in remote locations without power, whereas MTUs treat up to 22 gallons per minute and use an air stripper. Both CTUs and GTUs treat flows up to about 45 gallons per minute, but the former has an air stripper plus optional portable ion-exchange columns, and the latter pumps groundwater through granular, activated carbon to remove contaminants.

Groundwater Cleanup Using Aerogel/GAC Composites

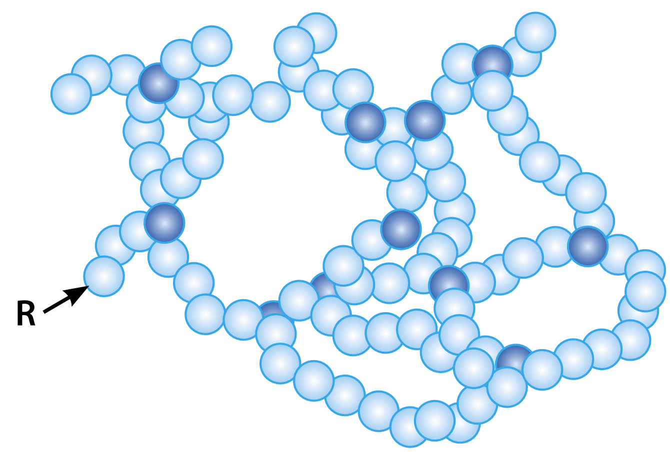
Aerogels are open, foam-like structures with very large surface areas (approximately 1000 m^2 per gram of aerogel), low densities, and high porosity. Granular activated carbon (GAC), used extensively in water treatment, is an abundant and inexpensive material that also has a very large surface area. We have been developing a process for adsorbing contaminants from water using functionalized aerogel/GAC composite materials. Our composites (Fig. 10) consist of approximately 10% hydrophobic silica aerogel and 90% virgin coconut shell GAC. Such composites can remove both volatile organic compounds (VOCs) and metals from water.

To date, we have demonstrated the removal of uranium, hexavalent chromium, arsenic, and several VOCs [such as trichloroethylene (TCE)] in laboratory tests using simulated groundwater. We have found, for example, that varying the phosphorous (P) in a P-enriched aerogel/GAC composite affects uranium removal. Figure 11 shows the adsorption isotherms for studies in which we varied the type and amount of phosphorous. A field test of our composite for adsorbing uranium (in the range of 300 parts per billion) from actual groundwater showed greater than 95% removal. We obtained similar results from field tests involving the removal of hexavalent chromium (in the range of 60 parts per billion) from a different groundwater that also had VOC contamination. Treated groundwater was below the detection limit of 2 parts per billion for chromium.

Although ours is not yet a mature technology—in the sense that it is not yet available at production scale—it has the potential to be competitive with other technologies now used for groundwater cleanup. For example, we anticipate that the production costs of aerogel/GAC composites will be competitive with those of existing technologies. The adsorption capabilities to date are orders of magnitude better that GAC alone for VOCs, and comparable to or better than existing technologies for removing metals. Aerogel/GAC composites can be used in an existing water-treatment infrastructure for GAC and may not be as expensive as enhanced coagulation and ion exchange. Moreover, because the composites represent a low-technology approach applicable to multiple contaminants—including organics, petroleum products, and metals—there is no need for extensively trained operators.

For further information, contact Sabre Coleman (coleman2@llnl.gov).

Figure 10. Aerogel/GAC composite materials are formed by mixing hydrophobic sol-gel precursors (R = $-CH_2CH_2CF_3$) with chemical agents, including those with iron and manganese, functional groups, and GAC. After gelation, the mixtures are dried to form aerogel/GAC composites.



Coconut shell GAC in H_2O

GAC as impregnated with Mn and Fe and hydrophobic silica aerogel in H_2O

Perchlorate Removal

Perchlorate is an environmental concern because it inhibits normal thyroid function. To address the problem, we have been developing a way to remove perchlorate (ClO_4^-) and nitrate (NO_3^-) from contaminated groundwater at LLNL. More specifically, we are evaluating a wetland bioreactor that shows good potential for long-term perchlorate and nitrate remediation in the field. Our experimental device has been operating continuously in a remote location with a stable ecosystem of indigenous organisms that degrade perchlorate and nitrate. A bioreactor is a "green" technology because it can be powered with renewable energy sources, such as solar or wind.

Our wetland bioreactor was constructed with two wetland plants, *Typha* and *Cyperus*, which provide habitat and carbon for microorganisms. Water flows through the wetland bioreactor with a hydraulic retention time of about 17 hours. Over a two-year period, we evaluated influent and effluent groundwater for reduction–oxidation conditions and for nitrate and perchlorate concentrations.

It is important to identify the dominant microorganisms that colonize sediments from different sample depths within the reactor to ensure that no undesirable microorganisms are being amplified. During the winter, we retrieved sediment samples from noncontinuous, vertical cores. Total community DNA was extracted and purified from 10-gram sediment samples. We used denaturing gradient gel electrophoresis analysis of short DNA PCR products to identify the dominant microorganisms living within the reactor. The bacteria genera that we identified were closely affiliated with bacteria that are widely distributed in soils, mud layers, and freshwater. Of the 17 dominant bands sequenced, we found that most were gram negative and capable of aerobic respiration or anaerobic respiration with nitrate as the terminal electron acceptor (*Pseudomonas*, *Acinetobacter*, *Halomonas*, and *Nitrospira*). Several identified genera (*Rhizobium*, *Acinetobactor*, and *Xanthomonas*) are capable of fixing atmospheric nitrogen into a combined form (ammonia) utilizable by host plants. We also identified isolates from the *Proteobacteria* class—a class of bacteria known for its widespread ability to reduce perchlorate. Our initial bacterial assessments of wetland bioreactor sediments confirm the prevalence of anaerobic bacteria capable of reducing perchlorate and nitrate *in situ*.

For further information, contact Paula Krauter (krauter2@llnl.gov).

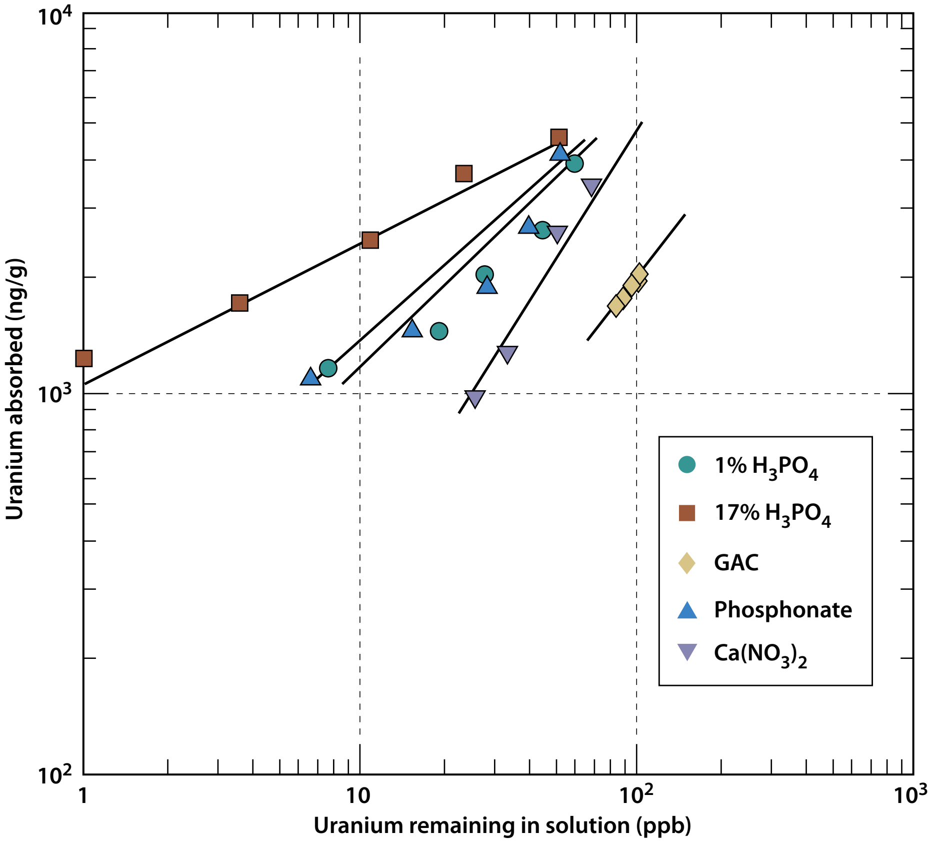


Figure 11. Uranium adsorption on phosphate-enriched aerogel/GAC composite materials. These results clearly show that the amount of uranium adsorbed on the composite increases with phosphorous enrichment compared to GAC without the composite.

Ecological Modeling of Risk to Vertebrates from Brine and Petroleum Spills

Petroleum exploration and production (E&P) sites are often located in rural areas that have diverse populations of mammals and birds. Spills associated with brine (containing salts) and petroleum (containing hydrocarbons) can affect terrestrial vertebrates not only through direct exposure to toxic compounds, but also through loss of reproductive habitat or reduced availability of food. Although data on the frequency of spills at E&P site are not always readily available, we know for example that approximately 900 brine spills per year were reported by the State of Oklahoma between 1993 and 2002. Researchers from LLNL and Oak Ridge National Laboratory (ORNL) have collaborated to investigate the role of disturbance patches on vertebrates at the Tallgrass Prairie Preserve in Osage County, Oklahoma, which is an E&P site. This work is funded by DOE Fossil Energy and involves investigators from the Environmental Restoration Division of the Environmental Protection Department, the Energy and Environment Directorate, and the Center for Applied Scientific Computing at LLNL.

Figure 12. The American badger (*Taxidea taxus*) is a voracious, solitary predator with low tolerance for other individuals.

Our research has two long-term goals. The first goal is to develop an ecological framework to evaluate impacts of brine or oil spills using population models based on the patchiness of the spills within landscape. Such patchiness can fragment the landscape as a result of vegetation and soil damage. The second goal is to develop thresholds based on the size and distribution of spills that would result in minimal impacts on wildlife populations. Such thresholds could be used as "exclusion criteria," and might be applied to exclude certain well or spill locations from formal ecological risk assessment. This type of approach may be useful in developing restoration priorities and strategies, or to help locate roads and the associated infrastructure in new exploration sites.

We have studied two vertebrate species: the American badger (*Taxidea taxus*, shown in Fig. 12, is the focus of ORNL work) and the prairie vole (*Microtus ochrogaster*, shown in Fig. 13, is the focus of LLNL work). We have constructed individual-based populations models for each species for use within our ecological framework. The two models emphasize different aspects of vertebrate ecology, such as habitat suitability and predator–prey relationships. The models can simulate population changes over time in response to a variety of disturbances, such as those by fire, petroleum spills, and brine spills. Our modeled events include local biological processes that influence individual animals (such as mortality, reproduction, aging, and mating choice) and external or landscape-wide events, including disturbances and the resulting redistribution of animals (see Fig. 14).

Even though our modeled results have not yet been verified in field studies, we can briefly summarize the results of the simulations to date. We found that the persistence of simulated American badger populations decreased with increasing brine spill area. The decline in persistence and average final population size was much steeper in highly fragmented landscapes. The simulated time to extinction for prairie vole populations showed a threshold at 30%


Photo courtesy of Ryan L. Rehmeier

Figure 13. The prairie vole (*Microtus ochrogaster*) is a monogamous herbivore that feeds on grassland vegetation and is preyed on by predators such as owls, badgers, and snakes.

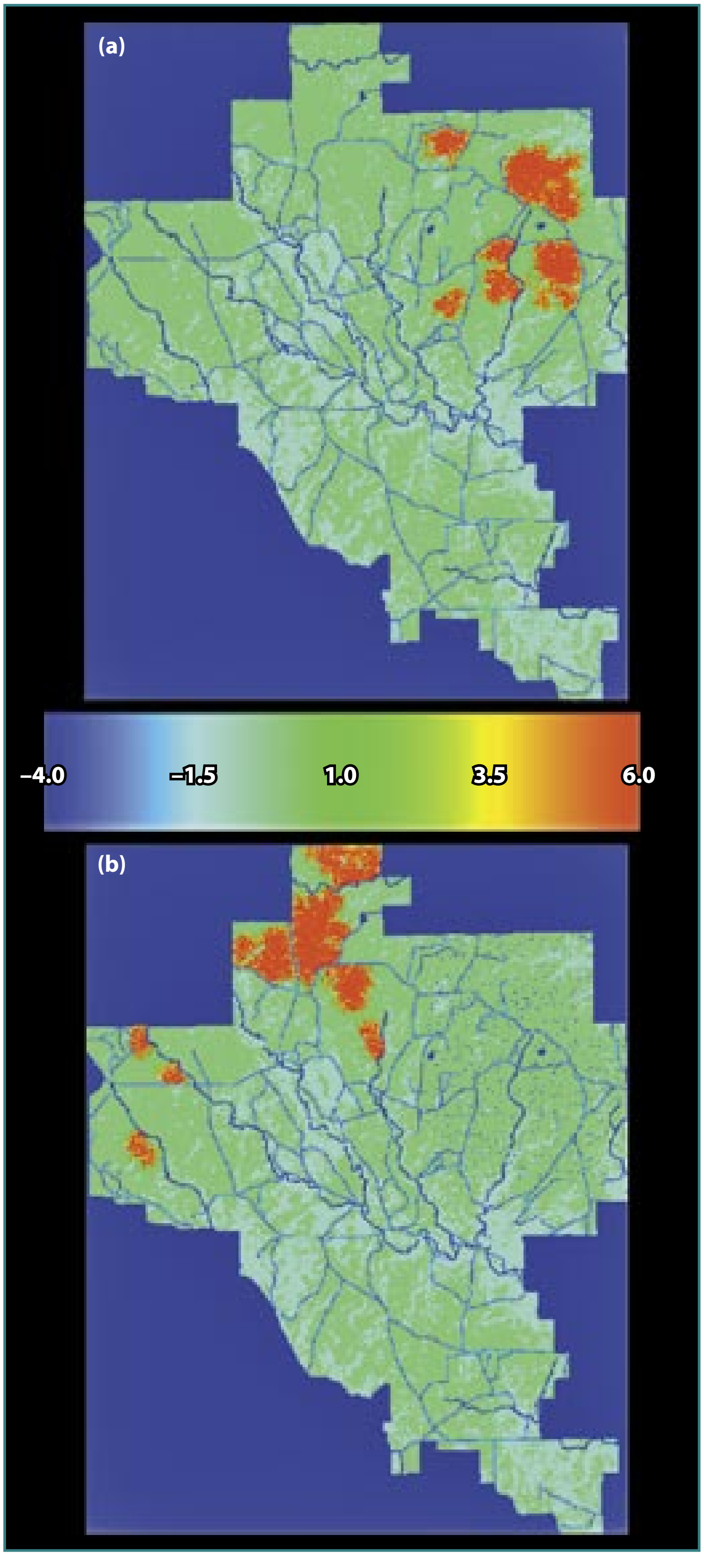


Figure 14. We investigated the combined role of spills and other sources of fragmentation on the persistence of vole populations at the Tallgrass Prairie Preserve. The simulations shown here include (a) a realistic representation of roads (blue), rivers (dark blue), and patches of nongrass vegetation (light blue), and (b) a distribution of 1000 artificial spills in the northeast portion of the preserve. Red represents areas of high vole density that change in location and size during the year.

habitat loss from spills. Above this threshold, the time to extinction decreased with increasing spill area. Vole density is sensitive to the interaction of predation and fragmentation, with fragmentation causing population extinction in the presence of predation, yet stabilizing the population in the absence of predation. We believe that studies such as ours may help focus scientific and regulatory attention on potential ecological impacts and away from potential toxicological impacts alone.

For further information, contact Tina Carlsen (carlsen1@llnl.gov).

New Fuel Additives

ERD personnel have played a key role in assessing the potential impacts of a new diesel fuel additive on California water resources. The product, called PuriNOx, was developed by the Lubrizol Corporation to improve emissions from diesel vehicles.

California Senate Bill 529 requires the California Environmental Policy Council to identify and evaluate all significant beneficial and adverse impacts on the environment that may result from any fuel specification proposed or established by the California Air Resources Board (CARB), including impacts associated with production, use, and disposal of the compounds that may be used to meet the specification. California Senate Bill 989 prohibits the CARB from adopting new fuel specifications until a "multimedia" evaluation has been performed and submitted to the California Environmental Policy Council for final review and approval. In the case of PuriNOx, the California State Water Resources Control Board (SWRCB) requires information that will allow an informed decision to be made regarding the relative risk of PuriNOx to California water resources and beneficial uses, as compared to ultra-low sulfur diesel.

In July, 2003, the Lubrizol Corporation submitted to the SWRCB and CARB a multimedia evaluation report for use of the proprietary PuriNOx diesel fuel technology in California. Lubrizol asked LLNL to conduct an independent review of data and the data analysis developed by Lubrizol regarding potential impacts to surface and groundwater that may result from the proposed use of PuriNOx fuel in California. The purpose of the independent review by LLNL was to assist the SWRCB in completing its evaluation of a multimedia assessment study of the use of PuriNOx fuel. To conduct this review, LLNL formed an independent, expert panel to perform third-party review of the PuriNOx data package provided by Lubrizol. Our report was completed in September, 2003. It will be used in making the final decision by the California Environmental Policy Council.

For further information, contact Harry Beller (beller2@llnl.gov).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Radioactive and Hazardous Waste Management Division

Introduction

Because of the nature and extent of its research and operations, LLNL generates hazardous, radioactive, and mixed (hazardous and radioactive) waste. The Radioactive and Hazardous Waste Management (RHWM) Division is the Laboratory's focus for implementing technologies necessary to manage in a safe and compliant manner all hazardous, radioactive, and mixed wastes generated at LLNL facilities. To that end, the RHWM Division continually develops and improves methods for managing such wastes to ensure that the environmental impact of byproducts is as negligible as possible. Our responsibilities include designing and acquiring new facilities as well as investigating new and more cost-effective methodologies for hazardous waste handling, stabilization, treatment, certification, and disposal. To carry out its responsibilities, RHWM must have the expertise to:

- Track and document hazardous, radioactive, and mixed wastes for the Livermore Site and Site 300.
- Process, store, package, treat, and prepare waste for shipment to licensed off-site treatment, storage, and recycling facilities.
- Provide technical support to generators during the generation and packaging of hazardous and radioactive waste to allow us to properly dispose of the waste efficiently.
- Ensure that LLNL meets federal, state, and local regulations regarding the permitting and compliance of RHWM facilities.
- Support the LLNL Waste Certification Program, which manages sampling and analysis for all low-level radioactive waste streams to ensure that requirements for off-site shipment are met.
- Respond to emergencies and participate in the cleanup of hazardous and radioactive spills at the Livermore Site and Site 300.

At the Livermore Site, RHWM has moved into a new, integrated facility for storing and processing LLNL wastes. The new facility, called the Decontamination and Waste Treatment Facility (DWTF), provides safe and cost-effective waste operations, and broadens overall internal waste management capabilities compared to the old facilities. The DWTF is described in more detail in the following article. RHWM still maintains operations in a limited set of the old facilities. An important consideration is that the new DWTF helps RHWM address LLNL's legacy waste issue. Legacy waste, in general, is waste that was generated before 1996. It can be mixed waste, low-level waste, or transuranic (TRU) waste. RHWM has received funding to characterize and dispose of legacy waste over the next two years. In the following technology highlights, we describe the DWTF, research on a new process to treat legacy waste, and other selected topics that demonstrate our balanced and forward-looking approaches to managing hazardous waste at LLNL.

For further information, contact Stephanie Goodwin (goodwin3@llnl.gov).

Technology Highlights

The New Decontamination and Waste Treatment Facility in Action

A byproduct of the Laboratory's national security missions is the generation of unusually diverse waste. LLNL has the responsibility to manage its waste from "cradle to grave" in ways that are safe and appropriate, meet all regulatory requirements, and address community concerns about environmental safety and health compliance. The Decontamination and Waste Treatment Facility (DWTF) is a new, integrated facility for storing and processing LLNL wastes, whether they are hazardous, low-level radioactive, transuranic radioactive, or mixed (that is, both chemically hazardous and radioactive). Opened for operation in September 2003, the DWTF provides safe, cost-effective waste operations and substantially broadens Livermore's internal waste-management capabilities. Both the design and implementation of the new DWTF match the waste management philosophy at RHWM, and its use is tailored to the needs of the Laboratory.

The new facility is a controlled area that includes a complex of buildings, outdoor containment pads for rainwater management and tanker storage, and a truck scale. The indoor storage areas and a California-permitted treatment plant are all connected to an impressive ventilation system. For treating wastes, a 2,200-m^2 building is used to process solid waste, and a 1,600- m^2 building is used to process liquid waste. Because most waste disposal sites charge by volume rather than mass, an important goal is to reduce the volume of waste. The DWTF is designed to compact and reduce the volume of both solid and liquid wastes. Solid wastes are shredded to decrease their volume, and liquid wastes are evaporated. The byproducts of evaporation are an aqueous waste suitable for sending down a sewer to the municipal water treatment plant, and a much-reduced volume of evaporator sludge that is solidified prior to off-site disposal in a regulated landfill.

The DWTF solid waste processing building is equipped with two 4.5-metric-ton bridge cranes that can move large items and drum crushers that can mash drums of all sizes into flat pancakes. A transuranic waste repackaging glovebox is used to open, repackage, segregate, and ready for disposal the contents of 55-gallon (200-liter) waste drums. The building has substantial storage along with an appropriate amount of space for general waste handling and packaging operations. The cranes offer the ability to move large equipment slated for size reduction and to load container arrays into special transport vehicles, such as tritium casks or the TRUpack II. Fork truck access into the solid waste processing area is through an airlock, which controls movement into and out of a radioactive handling area.

The centerpiece of the liquid waste processing building (see Fig. 15) is an enormous, enclosed tank farm with nine 17-kiloliter, closed-top tanks in an arrangement that offers many advantages over the previous open-air tank farm. Reagents are delivered directly into the new tank farm using an integrated system. Off gases generated during treatment can themselves be treated, an option not previously available. The DWTF offers greater control through an enhanced, programmable logic-control system. More monitoring can be done using augmented sensors, and waste streams are segregated through additional tanks and isolation plumbing. The liquid waste processing building includes a process-development laboratory that can be used for treatability studies, process verification, and small-scale treatment. The building also includes gloveboxes, fume hoods, and a high-ventilation room to process reactive and highly toxic materials.

The solid and liquid waste processing buildings share a ventilation system designed to control the direction of airflow throughout the facility. Ventilation air moves at a rate of 112,500 ft^3 per minute. With all doors closed, the difference between zones is 0.03-in. water-gauge pressure. With roll-up doors open for trucks, the pressure differential falls, but the direction of airflow is still into the building, not out. All air in the two buildings is fed through enormous banks of more than 90 high-efficiency particulate air (HEPA) filters before the air leaves through the stacks. Outgoing air is monitored to ensure that it meets all regulatory standards. Even the choppers and shredders have their own HEPA filters. Air is filtered first before being sucked into the building's ventilation system and filtered again at the main HEPA filter banks. A similar process occurs at the tank farm, where gases and organic vapors are routed to a special process off-gas (POG) system that handles approximately 13,000 ft^3 per minute of air. This system scrubs gases and uses carbon adsorption to eliminate acid gas and organic vapor. The advantage of an integrated ventilation system, and having operations performed in enclosed spaces, is that the public, workers, and the environment are all protected.

The DWTF uses conventional, tried-and-true techniques to treat wastes whenever possible. However, the Laboratory's waste streams can be unique, requiring individual attention and specialized treatment. An example is the spent and highly contaminated HEPA filters that require treatment before off-site disposal. Some are legacy filters, such as those used in gloveboxes, which are often defined as mixed waste because they are contaminated with both radioactive and hazardous constituents. Because effective and optimal treatment alternatives were unavailable, a team of LLNL waste-treatment engineers and technicians developed the patented *In Situ* Stabilization and Filter Encapsulation (IS*SAFE) process for safely encapsulating contaminants in used HEPA filters without generating secondary waste.

Figure 15. Many systems in the DWTF are computer controlled, including the off-gas system, evaporator, and tank farm. An engineer is shown here by the portable operating interface for the liquid waste processing area. At left in the foreground is the tank farm's central control panel that shows the condition of all tanks, including fluid levels, temperature, pH, conductivity, and oxidation–reduction potential, along with the status of pumps and valves. The computer program reads all inputs and outputs every 20 milliseconds and updates the color-coding on the panel, providing real-time feedback on the systems.

Clearly, there is no magic wand that one can wave to make the diverse wastes generated at LLNL transform themselves into benign forms or disappear. The DWTF offers a realistic and responsible solution to meet all regulatory requirements related to waste management now and well into the future.

For further information, contact Stephanie Goodwin (goodwin3@llnl.gov).

Waste Treatment Highlights

The division's multidisciplinary Waste Treatment Group (WTG) includes analytical chemists, process and environmental engineers, waste treatment technologists, programmers, maintenance and fabrication personnel, and a compliance analyst. The mix of skills is required to meet the waste treatment, characterization, analysis, and technology research mission of the division. During a typical year, the WTG treats approximately 36,000 gallons of aqueous and 240 m^3 of solid waste. The aqueous and solid wastes are radioactive, hazardous, or mixed waste that require treatment before being discharged to the municipal sewer system or being shipped off-site for land disposal in specially regulated landfills. Now that the DWTF is operational with its expanded treatment capabilities, we are processing and treating some of the more complex legacy waste streams that have been stored on site, awaiting opening of the DWTF. We will also continue to process and treat newly generated wastes.

Treating Complex Uranium Waste. Uranium is a silvery, metallic element found in the earth's crust in trace quantities. Uranium is a highly reactive metal because its valence electrons are easily oxidized. Because finely divided uranium powders can be pyrophoric (can burn spontaneously), such uranium wastes are typically placed in steel drums and are covered with either liquid coolant or water prior to storage. In addition to its characteristic radioactivity and reactivity, uranium metal is chemically toxic at high concentrations. Storage, treatment, and disposal of uranium wastes are strictly regulated to ensure that human health and environmental integrity are protected.

LLNL currently has an inventory of at least 11,700 kg (158 drums, 33 m^3) of pyrophoric uranium metal that requires treatment before disposal. With the opening of the DWTF, we now have approximately two years to treat all of the depleted uranium stored at LLNL to comply with regulatory requirements.

We have been investigating the treatment of depleted uranium for three years. An innovative process has been developed that will allow the treatment of this complex waste stream in the DWTF, using readily available equipment and chemicals. The process has several advantages over other proposed methods of uranium treatment. Our chemical treatment process:

- Poses fewer hazards than a thermal oxidation process.
- Uses readily available reagents that can be easily handled.
- Can take place in either batch or continuous-flow mode.
- Is applicable to multiple alloys and waste forms.

Our uranium deactivation process includes waste sorting (Fig. 16) and washing, uranium dissolution, and solidification. Uranium deactivation will be accomplished by dissolving metallic, depleted uranium waste in a solution of hydrochloric and phosphoric acid. The residual from the dissolution step is highly acidic and requires neutralization before solidification with a commercially available clay product. The final product from our innovative process is a solidified waste that can be disposed of in a regulated landfill.

← Preparing to collect samples from a drum of depleted uranium waste.

Weighing a sample of depleted uranium sludge prior to surveying the container. →

← Example of the types of large objects often found in drums of depleted uranium waste.

Recording the depleted uranium sampling activity. →

Figure 16. Waste technologists collect and weigh a sample of depleted uranium sludge, then record the results of the sampling activity.

We are preparing for startup of the full-scale unit by completing a series of intermediate-scale experiments. The studies will allow researchers to verify process thermodynamics. Another goal of the intermediate-scale studies is to allow WTG technicians to become familiar with the new process and the handling requirements of this complex waste stream. On completion of intermediate-scale studies and receipt of the processing equipment, we will tackle one of the last high-volume, previously untreatable waste streams on site.

For further information, contact John Bowers (bowers3@llnl.gov).

Debris Waste Treatment. The EPA defines many contaminated, solid materials that are intended for disposal as hazardous debris. Much of the waste that is generated and stored at LLNL meets the definition of hazardous or mixed-waste debris. The hazardous debris waste stream at LLNL includes equipment, laboratory waste, building materials, and used protective clothing (such as gloves, coveralls, and booties). Much hazardous debris is only superficially contaminated with hazardous or radioactive constituents. If the hazardous constituents are removed, the waste can be reclassified as nonhazardous or low-level waste (if it was previously a mixed waste) and can be disposed of more safely and economically. The inventory of legacy debris waste at LLNL is 181 m^3, making it one of the larger of the solid waste streams that must be processed. The cost of waste disposal is based on the volume of waste disposed, so a large reduction in disposal cost can be achieved if the volume of the waste stream can be reduced. We plan to treat contaminated debris in two stages: by shredding to reduce volume and then washing to remove hazardous contamination.

The DWTF is equipped with two, hydraulically driven, mechanical waste-shredding units to perform size reduction operations on a variety of solid wastes currently in the LLNL waste inventory, including contaminated debris. These units are driven by a remotely located, 75-hp, electro-hydraulic system that provides hydraulic pressure to the motors on each shredding unit. Shredder 1 has cutting teeth to perform crude cuts, and shredder 2 can make finer, strip-like cuts. Each shredder resides in its own room. The exhaust from each room passes through a dedicated bank of HEPA filters prior to passing into the DWTF building exhaust system for a second stage of HEPA filtration before discharge from the building. The shredding system allows LLNL to reduce costs by allowing tighter packing of shredded solid waste items.

We recently designed and installed a debris washer (Fig. 17) for treating hazardous debris to meet regulatory requirements for off-site disposal. The washer can treat many types of waste materials, including glass, plastic, metal, concrete, wood, and paper. The device uses chemical extraction technology to treat contaminated debris. After being loaded into the debris washer, debris waste is sprayed and washed with pressurized hot water. Surfactants, acids, or bases can be added to the water to enhance treatment, depending on the specific contaminants to be removed. After treatment, wash water is sampled and managed appropriately using other treatment units available in the DWTF. After the wash solution has drained, heated or unheated air is passed through the washing box to dry the waste. The air is then directed to the Process Off-Gas System (POGS) before being routed to the facility's pollution abatement system. After drying, the waste is prepared for shipment and off-site disposal.

For further information, contact John Bowers (bowers3@llnl.gov).

Water-Reactive Wastes. The volume of water-reactive wastes at LLNL is relatively small, but such wastes pose a fire hazard if handled or treated improperly. When water-reactive compounds are exposed to the atmosphere, they react with water moisture in the air to produce an hydroxide salt and hydrogen gas. The heat generated during this reaction is usually great enough to ignite the hydrogen gas, causing an explosion and fire. Using water to fight a fire involving water-reactive compounds makes matters worse because more fuel is added to the fire. The bulk of water-reactive wastes at LLNL include pure alkali metals, such as sodium or lithium, and metal hydrides, such as lithium hydride and uranium hydride. We are developing a process to treat reactive wastes in a safe and controlled manner using a specially designed reactor.

Figure 17. The debris washer is used to wash and dry hazardous debris. Following treatment, the debris can be reclassified as nonhazardous waste.

The 10- by 10- by 13-in. reactor to be used is double-walled with an internal stainless-steel reaction vessel and a window on the top and front for viewing contents of the vessel (Fig. 18). The reaction vessel, designed and fabricated by RHWM personnel, has an internal volume of approximately 10 liters, making it possible to treat up to one kilogram of waste per batch. The reactor is equipped with ports for adding reagents or removing spent solutions, a temperature sensor for monitoring the solution temperature, and a mixer.

This vessel is designed so the rate of reaction can be controlled by limiting the amount of water allowed to interact with waste in the reaction chamber. The reactor allows for two different methods of water addition. The first method uses humid inert gas (such as argon) as the source of water. The reaction rate is controlled either by varying the amount of water vapor in the gas or by keeping the water vapor concentration constant and varying the gas flow rate to the reaction vessel. The second method for introducing water is to deliver a concentrated sodium hydroxide solution to the reaction chamber. Reactive waste reacts with the water in the sodium hydroxide solution. The rate of reaction is controlled by varying the concentration of the solution: the more concentrated, the less water available to react with the waste.

The heat and off-gases generated during treatment can be safely managed with the reactor. During treatment, temperature inside the reaction vessel is monitored, and the reaction vessel is continuously cooled using chilled water. A mass flow sensor is used to measure the amount of hydrogen gas produced during the reaction. The temperature of the reaction vessel and the hydrogen flow rate are good indicators of how a reaction is proceeding, and they allow us to determine when reactions are nearing completion. Off-gases from the reaction are directed to the POGS before being routed to the facility's pollution-abatement system.

To ensure safe handling when transferring reactive waste to the reaction vessel, the treatment operation is conducted in a controlled atmosphere glovebox. The glovebox is filled with argon gas that is constantly circulated through a drying train that removes oxygen and water vapor. The drying train keeps the concentration of oxygen and water vapor in the glovebox to less than 5 ppm, which is too low to significantly react with the waste. Such waste-handling practices and controlled treatment techniques allow for the treatment of problematic waste streams in a safe, controlled, and efficient manner.

For further information, contact John Bowers (bowers3@llnl.gov).

Aqueous Low-Level Waste Evaporation. We have procured a low-temperature evaporator (cold vapor evaporator) to treat aqueous low-level radioactive waste by separating the radioactive constituents present in wastewaters generated during various LLNL research activities. The unit uses a refrigeration circuit to transfer heat energy into each of four reaction chambers. The transferred energy causes the waste liquid to boil, and the heat energy released during condensation of the distillate is captured by the refrigeration circuit and returned to the evaporation chamber, thus completing the cycle. Because the reaction chambers are under a vacuum, evaporation occurs at a temperature that is only about 60°F. The equipment has a throughput of approximately 100 gallons per hour and produces distillate clean enough to be released directly to the sewer without additional treatment. We can routinely achieve a volume reduction of approximately 95% with the new equipment. After evaporation, residual solids are removed manually, mixed with stabilization media, and solidified.

For further information, contact John Bowers (bowers3@llnl.gov).

Figure 18. An RHWM engineer talks with a machinist to ensure that the new reactive waste treatment unit is being built to design specifications. The new unit will treat up to 1 kg of reactive waste at a time.

Size Reduction Unit

The new Size Reduction Unit (SRU) located in Building 612 is a large, walk-in booth (Fig. 19) designed to facilitate the treatment and repackaging of wastes that are generated at LLNL, contaminated with radioactive or hazardous constituents, and slated for eventual disposal. Scheduled to begin operation in the autumn of 2004, the SRU is used for handling low-level waste, mixed low-level waste, and hazardous waste, as well as containers, tanks, and equipment contaminated with such waste constituents. As a Resource Conservation and Recovery Act (RCRA)-permitted treatment unit, both the types of materials and quantity of hazardous wastes allowed in the SRU are specified in the RCRA permit.

The SRU provides a workplace that controls airborne radioactive and hazardous materials generated from treatment and waste handling operations. Activities that can be conducted inside the SRU include opening containers as well as inspecting, sorting, packaging (repackaging, lab packing, and consolidating), and sampling contents. Dismantling—also known as size reduction—is done using hand-held tools that can be manual, pneumatically powered, or electrically powered. Manual decontamination is done with wipes, aqueous-based decontamination solutions, or other cleaning agents.

The prefabricated walk-in booth is constructed of stainless steel and has welded joints. Two equipment-access doors are located in the east wall of the booth to facilitate movement of equipment into and out of the booth. Personnel can enter the booth through a door located between the booth and an airlock. The working surface for size reduction and decontamination activities is a corrosion-resistant material laid over stainless-steel grating.

A separate, prefabricated airlock is attached to the north end of the booth. Constructed of durable materials, the airlock has interior surfaces suitably configured for decontaminating personnel. A door is installed on the east wall of the airlock to allow personnel to enter from adjoining Room 100. The airlock floor is constructed of grating made of durable, corrosion-resistant materials. A drain pan equipped with a drain valve and plumbing is installed beneath the grating. Secondary containment pans are installed under the floor in the booth and airlock. The secondary containment capacity is sufficient to meet hazardous waste regulatory requirements.

The SRU booth is maintained under slightly negative pressure by an induced-draft fan that discharges to the atmosphere through an exhaust stack. A 20,000-ft^3/minute HEPA filter system on the discharge of the vent system captures contaminants prior to discharge to the outside air. The SRU airlock is also maintained under negative pressure (less negative than the booth) and has an independent HEPA ventilation system.

Building 612 has an automatic, wet-pipe, fire-suppression system that provides protection throughout the building, including the interior of the SRU. The SRU booth and airlock also have an automatic, wet-pipe, fire-suppression system. Fire sprinklers are designed to fuse when heated, causing the sprinklers nearest a fire to activate and spray water over the fire. Water flowing through the sprinkler riser activates an alarm at the LLNL Emergency Dispatch Center, and emergency personnel, in turn, notify the LLNL Fire Department.

The SRU will offer enhanced capability for treating and repackaging waste. Previously, waste sampling, sorting, and repackaging operations were conducted in a HEPA-ventilated tent. The tent workspace was limited, providing only enough room for drum-sized waste packages. With the enlarged workspace offered by the SRU, waste activities can be expanded to include waste box packages measuring 4 by 4 by 7 ft, in addition to decontamination of medium-size equipment, such as gloveboxes. On completion of waste handling operations, decontamination of the workspace will be facilitated with the stainless-steel interior, an added bonus of the new SRU structure. With more room for waste and decontamination activities, the SRU will improve efficiency of operations and increase the safety of personnel.

For further information, contact Karen Doiron (doiron1@llnl.gov).

Figure 19. An RHWM technician reviews operating procedures associated with the Size Reduction Unit.

Repackaging Glovebox

We are installing a new repackaging glovebox in Building 696 that will allow radioactive solid waste containers to be opened and their contents examined, sorted, and repackaged. The glovebox is designed to reduce the likelihood of contamination and allows repackaged wastes to make the most of container capacity, lowering costs associated with off-site disposal.

As shown in Fig. 20, the glovebox is constructed of stainless steel and is approximately 15 ft long by 4 ft wide by 14 ft tall. Five workstations along each length of the glovebox, for a total of ten, have a set of glove ports and a viewing window so that up to ten people can work at one time. At one end of the glovebox, a 34-in. drum bag-in port with hydraulic drum lift holds and positions a drum to be sorted and repackaged. The glovebox floor has two specially designed bag-out ports where 55-gal drums can receive wastes that are being repackaged. Repackaging drums are supported on separate, moveable scissor-lift carts, each with a turntable and scale, which allows the drums to be properly positioned under the bag-out ports. At the other end of the glovebox is a 12-in. bag-in, bag-out port for removing samples and other small items, or for passing tools into the glovebox. A 1-ton electric hoist located along the roof of the glovebox assists in moving heavy objects. The glovebox is equipped with lights, internal tool racks, and a carbon dioxide fire-suppression system.

To prepare for waste repackaging, a container to be repackaged is supported in the horizontal position by the hydraulic drum lift located near the bag-in port. A large plastic sleeve is attached to the bag-in port at one end and to the container at the other end. The container is inserted into the glovebox so that it projects only a few inches beyond the glovebox wall. Receiving drums have a rigid poly flange and gasket assembly that seals to the two bag-out ports located on the floor of the glovebox. A plastic bag is installed into the receiving drums and attached to the poly flange on top of the containers. The bag provides a barrier between the internal glovebox atmosphere and the external environment. A plastic drum liner is placed inside the bag to keep wastes from puncturing the bag during drum loading. The scissor-lift cart, loaded with the drum and bag assembly, is wheeled under the glovebox, and the lift is raised to seal the drum to the glovebox.

A bag-over-bag technique is used for adding new containers to the glovebox, which ensures glovebox integrity. A new receiving drum uses a new flange and bag assembly that pushes the old flange assembly out while continuously providing a seal between the external atmosphere and glovebox.

To meet waste-verification requirements, three video cameras are mounted on the glovebox. Two monitor what is being deposited into the two receiving drums, and the third camera monitors work being conducted inside the glovebox. The glovebox remains under a slight vacuum to ensure worker safety. Exhaust from the glovebox passes through a HEPA filter mounted on top of the glovebox, and then passes through another housekeeping HEPA filter. Exhaust is routed to the building ventilation system where it passes through yet another series of HEPA filters before being discharged to the atmosphere. Such redundancy in filtration provides a high level of safety for workers and the community. Designed to meet even the most stringent acceptance and waste-disposal requirements, the new repackaging glovebox is a good example of our determination to conduct all waste management operations in the safest manner possible.

For further information, contact Harold Rogers (rogers22@llnl.gov).

Figure 20. The new RHWM repackaging glovebox is shown here with the drum bag-in port and hydraulic drum lift located on the left.

Waste Characterization and Verification Laboratory

The Waste Characterization and Verification Laboratory at the DWTF provides real-time analyses of metals, volatile organic compounds (VOCs), and radioactive samples to aid in treating mixed and radioactive aqueous wastes. This laboratory supports waste treatment operations, the development of treatment processes, and the small-scale treatment laboratory where treatability studies are done. As shown in Fig. 21, the laboratory houses the following instruments:

- Perkin-Elmer, Optima 4300 DV, inductively coupled plasma, optical emission spectrometer (ICP-OES).
- Gamma-ray spectrometer (“The Inspector”).
- Alpha spectrometer 7401.
- HP gas chromatograph/mass spectrometer (GC/MS).
- SRI gas chromatograph 8610.
- Tri-Carb 2770, liquid scintillation counter (LSC).
- MiniPal PW 4025, x-ray fluorescence (XRF) spectrometer.

To analyze metals, we can use two instruments of varying capabilities. The Perkin-Elmer Optima ICP-OES is a high-resolution spectrometer that uses plasma to excite elemental electrons, which produce photons unique to each element. It can detect and measure all elements except argon because argon gas is both the intermediate gas and carrier gas. This device is often selected for quantitative analyses of metals. The Philips Analytical MiniPal XRF is a compact, energy-dispersive, x-ray spectrometer designed for qualitative analyses of metals. The spectrometer can detect and measure elements in a wide variety of samples, such as metals and alloys, fused beads, pressed powders, and liquids. Because no sample preparation is required, the XRF spectrometer provides a fast and convenient way to analyze metals.

The HP GC/MS and SRI gas chromatograph 8610 are designed for analyzing VOCs either by direct injection or automatic sampling. The GC/MS has an HP 6890 gas chromatograph directly coupled to an HP 5973 mass spectrometer. The SRI gas chromatograph uses the purge-and-trap method to analyze VOCs and has three detectors for analyzing liquid samples that may be too dirty for analysis with GC/MS.

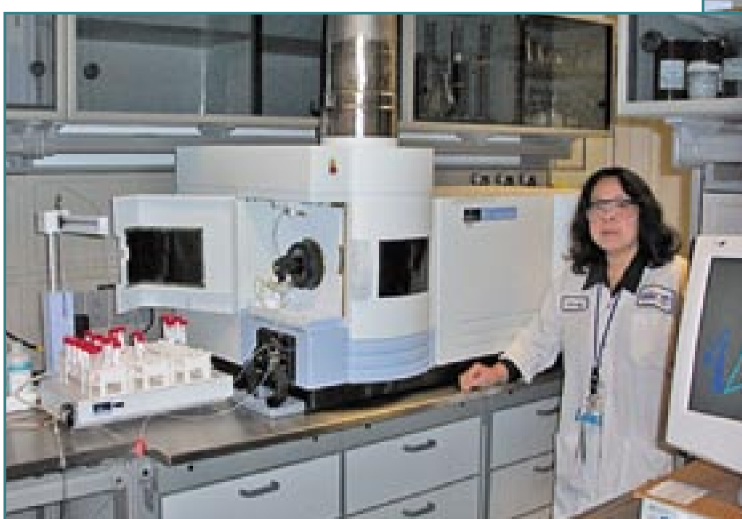


Figure 21. RHWM chemists operate a variety of state-of-the-art, analytical instruments while supporting waste treatment operations and treatability studies.

Clockwise from top left: Inductively coupled plasma spectrophotometer; Gamma-ray spectrometer, “The Inspector;” Alpha spectrometer 7401; and Gas chromatograph/mass spectrometer.

The Tri-Carb 2770 LSC is designed for quantifying radioactivity on a wide variety of samples, such as filters, membranes, solutions, and swipes. The instrument uses the patented, time-resolved, liquid scintillation counting (TR-LSC) method. This state-of-the-art instrument is equipped with a special detector, has very low background, and is ideal for analyzing environmental samples that have very low levels of radioactivity. Thus, it is used mainly to determine if a waste sample is radioactive and provides a qualitative way of doing radiological analyses. If we need to identify specific radionuclides in samples, then we use the gamma and alpha spectrometers. The Inspector is a portable, multichannel analyzer to determine gamma-emitting nuclides in waste samples. It has a germanium detector to analyze different sample matrices and geometries. The alpha spectrometer uses a PIPS detector for detecting alpha-emitting nuclides in waste samples.

In addition to the aforementioned work, the Waste Characterization and Verification Laboratory supports LLNL's legacy waste project, the characterization of unknown samples and chemicals left by retired scientists and technicians, and verification of other suspect wastes destined for eventual disposal.

For further information, contact Corry Painter (painter2@llnl.gov).

Fingerprint Verification Laboratory

Our Fingerprint Verification Laboratory (FVL) is unique in that it provides information and types of analyses that are not available from certified analytical laboratories or other sources at LLNL. A principal role of the FVL is continued support of the Waste Acceptance Plan criteria in LLNL's RCRA waste permit, which includes analysis of internally profiled waste streams. Along with various types of verification analyses, the FVL has expanded its support for other Environmental Protection Department activities. Examples include:

- Analytical determinations for the Environmental Operations Group to ascertain properties, contamination, or constituent levels in new waste streams.
- Radiological determination of LLNL construction soils (Fig. 22).
- Analysis of rainwater collected from berms.
- Characterization analyses not available from other internal or external laboratories, such as hexavalent chromium analysis of solid materials and x-ray fluorescence of liquids, solids, and oils.
- Analyses to demonstrate the characteristics or properties of waste items, such as batteries, incandescent light bulbs, circuit boards, and monitors.

Clockwise from top left: SRI gas chromatograph 8610; Tri-Carb 2770, liquid scintillation counter; and X-ray fluorescence spectrometer.

Figure 22. The FLV's Tri-Carb Liquid Scintillation Counter can screen samples originating in Radiological Materials Management Areas, is used for screening verification of treatment liquid, and makes radiological determinations of construction soils at LLNL.

Because of the quick turnaround times and cost effectiveness associated with these and other activities, the FVL provides a unique service to the Environmental Protection Department and LLNL programs.

For further information, contact Tony Be Lue (belue1@llnl.gov).

Addressing the Problem of Legacy Waste

Legacy wastes at LLNL date from the early 1980s. The Laboratory currently has 106 m^3 (820 drums) of TRU waste, 1223 m^3 of low-level waste (LLW), and 464 m^3 of mixed LLW. The LLW and mixed LLW wastes are stored in approximately 6,000 containers and are categorized into 32 waste streams. More than half of the LLW and mixed LLW wastes are laboratory trash. Other legacy waste streams include HEPA and other types of filters, scintillation vials, soil contaminated with elemental mercury, pyrophoric uranium, and reactives.

Legacy wastes were generated and stored at the Laboratory before a full waste-characterization program was established in 1999–2001. We have mounted a 24-month campaign to dispose of all LLNL legacy waste by the end of FY 2005 (Fig. 23). The DOE has mandated the accelerated schedule to refocus on complex-wide risk reduction and project closure. The refocus supports the expeditious transfer of Environmental Management operations to the National Nuclear Security Administration.

LLNL was able to accelerate its schedule by using a three-pronged approach involving:

- Risk-based management practices.
- New technologies developed at LLNL that are now being applied in the DWTF.
- Off-site commercial treatment and disposition facilities.

We are using risk-based management practices to evaluate the potential for high radioactivity levels and the presence of isotopes of special concern. This approach groups wastes by the building of origin. A risk level is then developed from information on the isotopes known, or possibly used, in a particular building. Such an approach allows characterization steps to be tailored to what might be in the containers. For example, if only uranium was used in a building, then the containers from that building are grouped and statistically sampled. In some cases, wastes from specific generators are identified for characterization.

LLNL now has a suite of techniques available to characterize wastes for treatment and disposal. Some containers are sampled for chemical analyses. Many laboratory trash containers are examined by x rays using real-time radiography (RTR). Of particular concern are items prohibited by the disposal sites, including sealed sources, aerosols cans, free liquids, and circuit boards. LLNL researchers developed a gamma counter for screening HEPA filters, and the device has been adapted to screen drums. We use a nondestructive assay technique to measure a broad range of isotopes, and a field gamma-measurement device for large boxes.

Thirteen wastes streams that are being treated in the new DWTF include aqueous liquids, gas cylinders, debris, and soils. Four waste streams, plus pyrophoric uranium, reactives, and radioactive compounds, will be treated using a technique developed from a Laboratory Directed Research and Development project. For more details about such treatment, see the article, "Treating Complex Uranium Waste," in the Waste Treatment Highlights section of this publication.

Some waste streams (190.79 m^3, or 12% of all our legacy waste) are extremely difficult to treat. We are currently evaluating off-site disposition and treatment approaches to determine the most cost-effective way forward.

Our TRU wastes are being characterized and certified for shipment to the Waste Isolation Pilot Plant (WIPP), located 26 miles southeast of Carlsbad, New Mexico. Mobile vendors worked with the RHWM staff to characterize and certify the waste. Equipment was brought on site to perform RTR, head-space gas sampling, nondestructive assay, and visual inspection. The waste must be characterized and certified to meet WIPP Waste Acceptance Criteria. After the TRU waste is characterized and certified, it will be loaded into special shipping containers (called the TRUPACT II) and shipped to the WIPP for disposal. This operation went through a DOE Operational Readiness Review.

In the future, the Laboratory will be required to implement the new DOE order that does not allow the generation of waste for which there is no disposal option.

For further information, contact Stephanie Goodwin (goodwin3@llnl.gov).

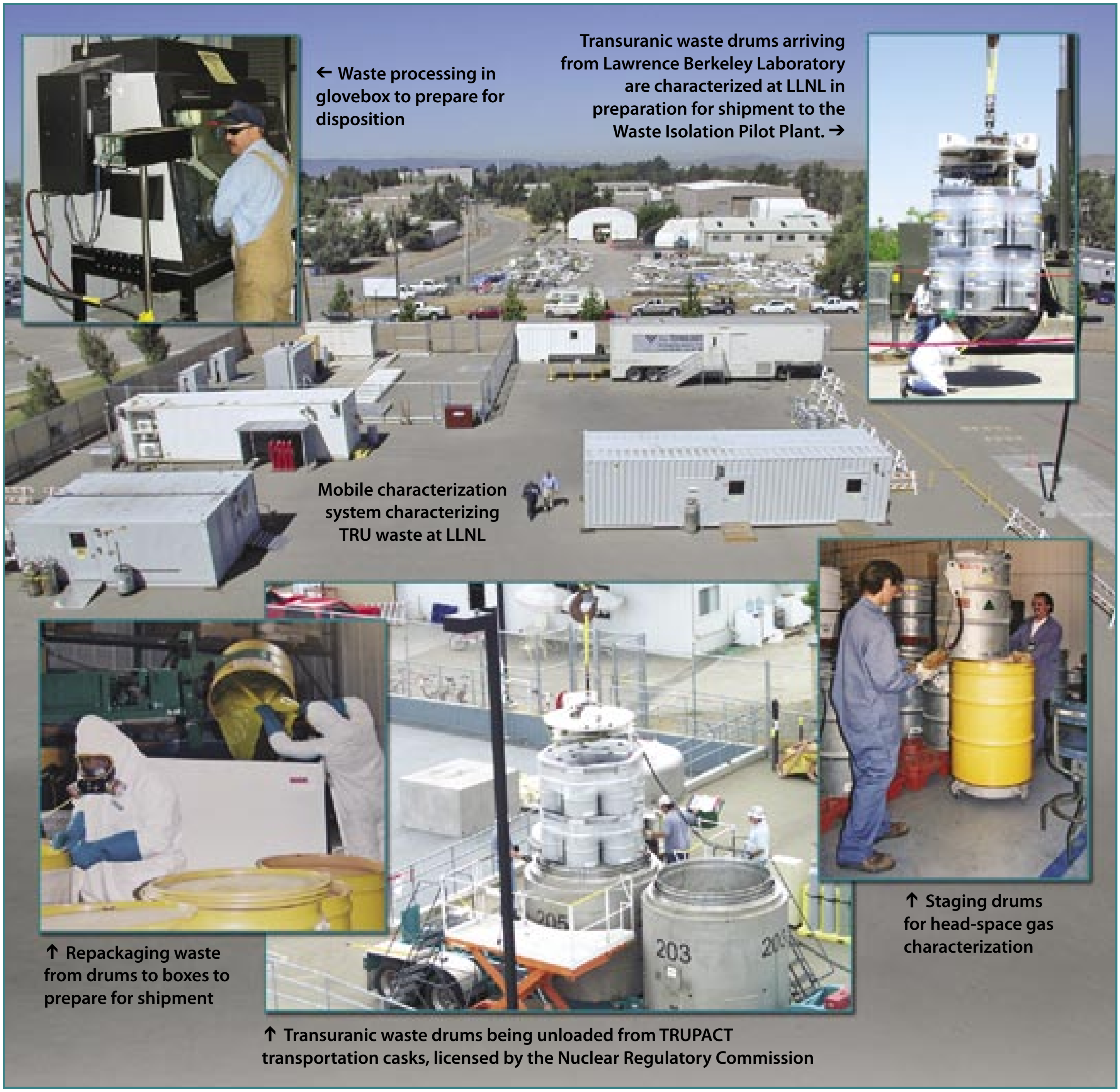


Figure 23. LLNL is disposing of its legacy wastes, including transuranic wastes, low-level wastes, and mixed wastes, an important milestone in preparing for turnover of Environmental Management operations to the National Nuclear Security Administration. The wastes need to be characterized and sometimes repackaged before transportation to an off-site disposal facility.

Operations and Regulatory Affairs Division

Introduction

The primary responsibility of the Operations and Regulatory Affairs Division (ORAD) is to assist LLNL in complying with environmental regulations. ORAD provides LLNL personnel with the guidance necessary to understand and implement environmental requirements and obtains the environmental permits that govern LLNL operations.

ORAD personnel use surveys and other field efforts to ensure the appropriate protection of natural and cultural resources during Laboratory activities. We develop and apply monitoring techniques, source evaluations, and computer modeling to evaluate the effect, if any, of LLNL operations on public health and the environment. Monitoring results are also used to help identify, quantify, and thus minimize or eliminate releases having environmental impacts.

The expertise of the ORAD staff in the regulatory and applied environmental fields allows us to develop new methods and innovative technologies. In addition to applying this information to improve environmental practices at LLNL, we are able to assist external organizations with environmental activities.

ORAD's responsibilities include:

- Helping Laboratory organizations comply with environmental regulations by sampling, reviewing activities for environmental aspects, and providing regulatory interpretation and guidance.
- Identifying opportunities to prevent the generation of waste.
- Writing environmental evaluations, applications, and documentation for submittal to DOE and regulatory agencies.
- Monitoring air, groundwater, wastewater, surface water, vegetation, food, and soil to ensure that the Laboratory is complying with all federal, state, and local regulations, and to determine the Laboratory's impact, if any, on the local environment.
- Conducting surveys and assessments of impacts to sensitive natural and cultural resources.
- Responding to environmental emergencies.

For further information, contact Charlene Grandfield (grandfield1@llnl.gov)

Technology Highlights

Risk-Based Evaluation of Environmental Compliance

Environmental regulation is a complex and evolving issue in that requirements frequently change, as do the policies and practices that are adopted within an organization to meet them. A major challenge for leadership is to address the environmental compliance dilemma as an ongoing process: ensuring that the intent of environmental laws and standards are always met, but avoiding actions that can misinterpret objectives and fail to produce outcomes for which an environmental compliance program was originally created. The Environmental Protection Department is implementing changes to many environmental-compliance programs at the Laboratory. The immediate need for change originated from a survey of LLNL programs showing that environmental management personnel were sometimes perceived as over-regulating or too isolated from the institutional programs they served. In response, a departmental task force established four goals designed to re-evaluate the ways that environmental requirements were being met.

The newly devised risk- and performance-based approach to environmental management involves (Goal 1) reassessing each environmental compliance program through an objective screening process using 16 specific, weighted questions, and then (Goal 2) prioritizing areas that should be evaluated further. Candidate areas are (Goal 3) evaluated for ways to save costs

Bounding criteria	Degree of risk				
	Very low	Low	Moderate	High	Very high
Laws, regulations, and standards (LRS)	No LRS in place. No logical driver behind current action.	Not counter to any LRS. Change corrects an overly conservative interpretation.	Changes interpretation of LRS, but oversight agency will likely accept the change.	Meets intent of LRS, but full agreement of overseeing agency is not likely. Could result in violation.	Likely to be challenged, and could result in "cease and desist," permit recession, or fines.
Operational considerations	Reduces impact to schedules or costs.	Negligible effect on schedules or costs.	Could affect schedules or require added resources.	Would increase resource requirements or impact schedules without benefit.	Changes will stop the program's work.
Fiscal and technical limitations	No cost increase.	Requires minimal resources (<$5K) or staffing time.	Requires more technology or moderate resources (up to $10K) or staffing.	Requires up to $50K in resources, or significant staff time, or use of experimental technology.	Requires >$50K in resources, added staff, or creation of new equipment or technology.
Perceptions[a]	Improves current stakeholder perceptions.	Changes will be accepted by stakeholders with little concern.	Negative perception likely by only 1 stakeholder.	Negative perception likely by more than 1 stakeholder; damage to reputation.	Damages the institution's reputation, or a high probability of lawsuit
Safety and health concerns	Beneficial, or no impact to environment, safety, and health of workers or public.	No impact to safety and health, but requires changes to health and safety manual, or new administrative or engineering controls.	Could have an increased impact on environment, safety, or health to levels below stated standards or guidelines.	Increased impact to environment, safety, and health. New administrative or engineering controls needed to reduce impact to within standards or guidelines.	Will increase impact to environment, exposure risk to workers or public, or adversely affect safety. No new administrative or engineering controls can reduce impact within standards or guidelines.

[a]A stakeholder is any person or organization with a reasonable interest in the project, including regulators, local agencies, activist groups, and community members.

Figure 24. The risk-impact matrix is used to assess LLNL environmental-compliance programs selected for evaluation. A change in the green zone means it could be implemented with concurrence of a group or division leader. The red zone means a change is inappropriate or requires legal review. The yellow zone means further evaluation is required by department management and possibly legal or auditor review.

and time using a standardized risk-impact matrix (Fig. 24) that is designed to ensure that environmental requirements are met while avoiding overly conservative interpretations. The effectiveness of implemented changes is (Goal 4) tracked, and recommendations for improvement are provided to responsible individuals.

An important objective in developing the new risk-based decision process was to create a standard tool that could be uniformly applied and defended during an in-depth review of the consequences of proposed changes to LLNL's environmental programs. Such a process can be used for both existing and new environmental programs at LLNL identified as having the potential for risk-based changes. Proposed changes are tailored to each environmental program selected as a candidate for review. Suggested actions include ways to improve schedules or perceptions about an environmental program; to reduce time commitments, costs, oversight, or required paperwork; to simplify the environmental program; or simply to adapt to flexibility in requirements.

A key concept in our approach is that "risk" does not mean increasing the chance of injury to health or damage to the environment. Rather, the term is used in the management vernacular and means balancing efficient business practices without unnecessarily strict interpretation of environmental laws, regulations, and standards. The issue is whether working assumptions about environmental requirements are accurate, and whether environmental policy is being implemented in the most efficient way possible.

Our new screening process identified 128 environmental programs at LLNL that were appropriate for further evaluation. We found that 9 of these programs had a major impact on Laboratory activities as a whole; 10 programs that were allowed regulatory flexibility exceeded minimum regulatory requirements; 10 programs were based on standards other than environmental law or industry standards; 23 exceeded minimum regulatory requirements or industry standards; and 31 cost more than $100K to implement and either were allowed flexibility or were based on standards other than an environmental law. We prioritized the results and were quickly able to recommend which of the programs should be evaluated first. To date, six of seven identified environmental programs within LLNL's Environmental Protection Department, and 14 additional environmental programs at the Laboratory have been evaluated.

In less than two years, the evaluation process has resulted in cost avoidance at LLNL as great as several $100K for some LLNL environmental-compliance programs, and cost savings ranging from several thousand dollars to about $100K for other programs. As an example of how the process works, we challenged the discharge compliance point at LLNL for hexavalent chromium. Our recommendation, that the compliance point be each groundwater treatment facility rather than at a location of combined flow, avoided approximately $400K per year. Several other recommendations center on paperwork, training, and information-tracking requirements. As one example, we negotiated with the DOE a simplified process for documenting National Environmental Policy Act (NEPA) coverage for some proposed projects, using a single-page form for the Record of Review, and using a consultation process to speed DOE review of NEPA coverage. The approved changes will reduce preparation and processing time by decreasing paperwork and review requirements.

Although our revamped decision process was developed in the context of environmental management activities at LLNL, we believe that the approach we have developed can be more widely applied to benefit other management areas. In fact, the entire process can be viewed as a risk- and performance-based management approach to evaluate any compliance function that is driven by external regulations or other standards.

For further information, contact Sav Mancieri (mancieri1@llnl.gov).

New Approaches to Environmental Modeling

To demonstrate LLNL compliance with federal, state, and local laws or regulations, and to complete dose and risk assessments for permits and operational planning, we use a variety of computer models. Some of the models are required by regulations; others are not. For example, the EPA currently requires the use of a model called CAP88 to demonstrate compliance with radionuclide National Emissions Standards for Hazardous Air Pollutants (NESHAPs). In contrast, we use HOTSPOT and EPICode to evaluate risks associated with hypothetical, worst-case release scenarios during the decontamination and demolition of older facilities because those models have less complex requirements for entering wind data. HOTSPOT and EPICode can also estimate the effects of accidental releases. Nevertheless, we prefer to use the more sophisticated model developed by LLNL's National Atmospheric Release Advisory Center (NARAC) to evaluate accidental releases. Because the NARAC model includes terrain effects and detailed meteorological data, it gives us more state-of-the-art estimates of the dispersion of a release.

Although use of CAP88 is currently required to show compliance with radionuclide NESHAPs, the EPA is sponsoring development of another model for this purpose, called GENII-NESHAPs. This is a modified version of the GENII model. EPA approval for use of GENII-NESHAPs in compliance is expected in 2004. Even though it has the same mathematical underpinnings for air dispersion (the Gaussian plume model), air concentrations predicted by CAP88 and GENII-NESHAPs will not be exactly the same because all other particulars of the models are not the same. For example, the two models treat calm winds and plume rise differently. Moreover, GENII-NESHAPs has more detailed exposure pathways and uses more recent dose-conversion factors. Such differences will affect the final calculated result, which is the dose or risk to an individual or population.

Because GENII-NESHAPs incorporates more up-to-date dose-conversion factors, we intend to use it to demonstrate NESHAPs compliance in the future. To prepare for the change, we have been exploring the differences in predicted concentrations and doses between CAP88 and GENII-NESHAPs. For example, we compared tritium (HTO) concentrations and doses for a unit release of HTO while making all other input as identical as possible. Figure 25(a) shows the results of our comparisons for 16 wind directions at three distances. Although the two models predict similar tritium concentrations in air in most directions, we found the greatest differences in the nonprevailing wind directions. Similarly, tritium doses predicted by GENII-NESHAPs and CAP88 are most different in the nonprevailing wind directions, as shown in Fig. 25(b).

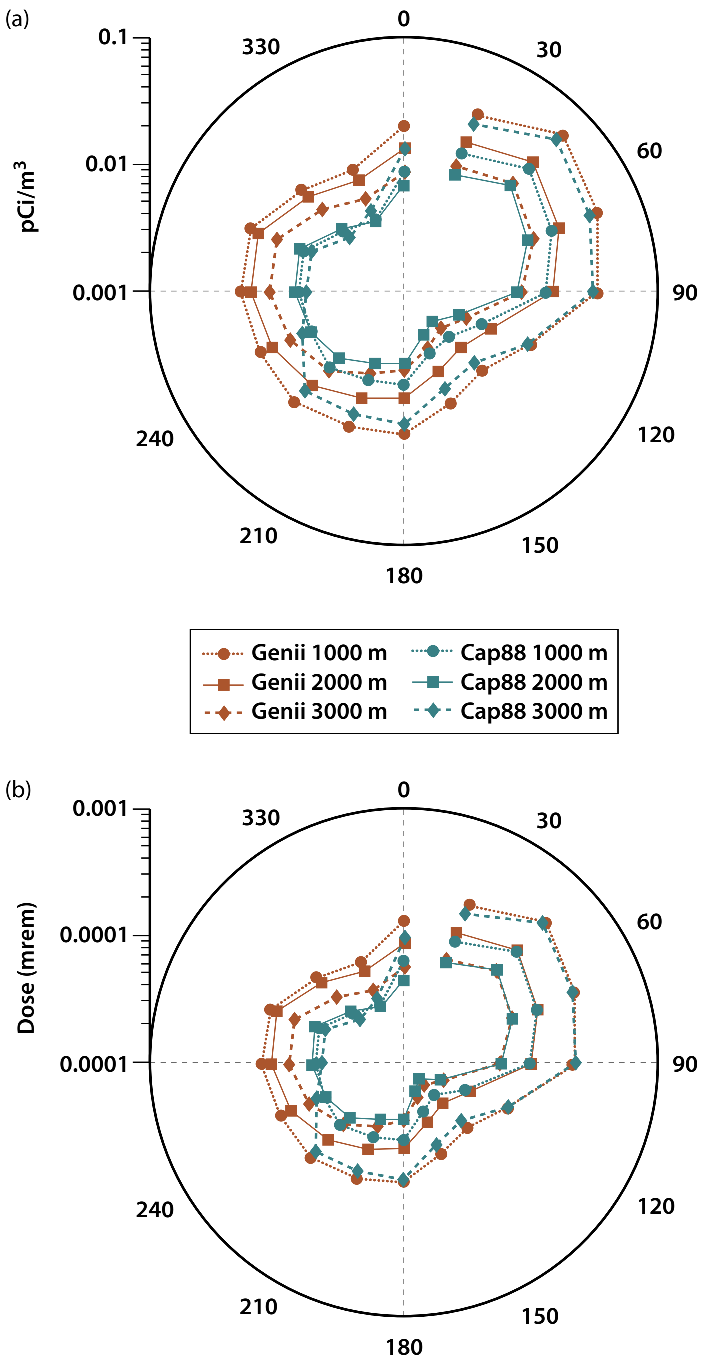


Figure 25. Predicted (a) air concentration of tritium (HTO, in pCi/m^3) and (b) dose from tritium (in mrem) for the CAP88 versus GENII-NESHAPs models. Results are shown for 16 wind directions at three distances (1,000, 2,000, and 3,000 meters from a source). Predictions for the two models are similar, with the greatest differences found in nonprevailing wind directions.

To address a different issue related to tritium dose modeling, we developed another tritium dose model, called Doses from Chronic Releases of Tritium (DCART). DCART is a stochastic model that predicts a realistic (or slightly conservative) annual mean dose—with the 95% confidence interval on that dose—to an adult, child (age 10), and infant (age 6 months to 1 year). We developed DCART to calculate annual doses over the Laboratory's history to a hypothetical individual located at the LLNL Discovery Center from releases of tritiated gas (HT) and tritiated water (HTO) to the atmosphere. We used site-specific data when available. The Discovery Center was chosen as the location of the hypothetical exposure because it is adjacent to the location of LLNL's site-wide maximally exposed individual, and concentrations of tritium in air have been sampled there biweekly since 1974.

Historically, more tritium than any other radionuclide has been released to the atmosphere from LLNL, and its radiological dose to a member of the public has been greater than that from any other radionuclide. In the past, dose predictions were made using different methods, models, and assumptions, but none accounted for uncertainty about the input. Furthermore, none of the previous dose assessments accounted for dose from organically bound tritium (OBT) in the diet or the contribution to dose from conversion of HT to HTO in the environment after releases of HT. Using DCART, we will generate a set of dose predictions that will be consistent and defensible. We also expect to define an upper dose limit that will be exceeded no more than 2.5% of the time.

For further information, contact Gretchen Gallegos (gallegos3@llnl.gov) or Ring Peterson (peterson49@llnl.gov).

Real-Time Monitoring Network

In 2001, we implemented a state-of-the-art, radiological monitoring system for LLNL's Livermore (main) Site. The system is designed to alert LLNL emergency managers to excess radiation levels, including a release of airborne radioactivity. We are expanding the monitoring network to incorporate active, real-time air monitoring for chemical agents and alpha radioactivity. The new, three-component system is now designated as the Real-Time Monitoring Network (RTMN), and it includes the Geiger–Mueller sensor detection system as the Real-Time Radiation Area Monitoring (RTRAM) sensor network. LLNL's expanded RTMN will boast three emergency-alert systems. The network components are:

- Sixteen Geiger–Mueller area sensors.
- Four chemical warfare agent (CWA) air monitors.
- Four alpha-spectrometer, environmental continuous air monitors (AS-ECAMs).

The 16 area sensors are spaced around the perimeter of the LLNL main site. Air monitors are in sets co-located at four locations. Figure 26 shows one such deployment platform.

Recent upgrades to the RTMN include data-driven modeling parameters for the RTRAM sensor network. We added automated alarm mechanisms and can now provide comparative modeling analysis using dynamic data for combined radiological and meteorological parameters. Analytical determination of an airborne event is reliably done for consequence management and enables an assessment team to manage any health threat to site personnel or the general public.

The RTRAM sensor network has a dynamic alert system for all airborne radiological activity. The data-driven parameters of LLNL meteorological and radiological data are displayed with a site plume overlay, as shown in Fig. 27. This is the first step in determining an airborne radiological event.

The CWA units (Fig. 26) use an ion-mobility spectrometer to detect chemical agents in the surrounding air. Each unit determines the ratio of ion velocity in the air to the magnitude of an electrical field created by a chemical signature (the ion mobility). Specific chemical agents have unique signatures of mobility spectra, and a library of the signatures has been loaded into the detector software. The software was redeveloped and refined as a result of lessons learned from chemicals detected during the Gulf War.

The CWA detection process involves collecting an ambient air sample though an inlet port. Air vapors then pass through a permeable membrane into two different detection cells. One cell detects nerve agents, such as the G agents (for example, GB or sarin). The other cell detects H agents, such as mustard gas. The detector uses an onboard microprocessor coupled with sophisticated software for agent identification and then assigns a hazard level depending on the type and concentration of the agent. Hazard levels signify when a shelter-in-place response may be necessary and when an area is safe to reenter. Historically, the detection of chemical vapors required personnel to enter the area to collect a sample, thereby placing them at risk.

In the event of an alarm, the detector immediately sends data to a control computer that provides a graphic displaying which detector is sending the alarm, the specific agent, and hazard level. An audible alarm at the detector site can be triggered, and additional notifications, such as automatic paging or control functions, can be made. For our systems, such a control function is to automatically collect a whole-air sample allowing potentially contaminated air to be later analyzed more rigorously in the laboratory.



Figure 26. Advanced platform with chemical warfare agent sensor and alpha-spectrometer environmental continuous air monitor. Close-up photos show the contents of the CWA detector (open box) and a different view of the alpha spectrometry ECAM sensor unit.

At present, our CWA units detect eight different chemical warfare agents. LLNL is working closely with the developer of the instrument to include additional industrial chemicals in use by LLNL, such as chlorine and phosphine. We are planning to incorporate the real-time system into the emergency response tools for use in the LLNL Emergency Operations Center.

The AS-ECAM detector (Fig. 26) is an active air-sampling system used to reliably determine the air concentration of alpha radioactivity in the presence of natural uranium decay products. Integrating this system to the RTMN will provide air concentration and isotope identification for emergency management and consequence assessment. The ECAM incorporates the latest technological advancements. The 1700-mm^2 passivated, implanted, planar, silicon detector head is seated above a filter housing to ensure 2π radian coverage. The unit sensitivity is 2 derived air concentration (DAC) hours, and it can signal and alarm at an acute interval in 30 seconds. The unit can run continuously for one week before requiring a filter change. The AS-ECAMs in our network are calibrated for the region of interest for transuranic elements.

Data from the expanded RTMN network of sensors are processed via a host computer residing in the LLNL Emergency Operations Center. Data are also stored in a database for each sensor and dynamically processed for web-based access by subject-matter experts. In the event of a real emergency involving a chemical or radioactivity release at the Livermore Site, the real-time network provides the Emergency Operations Center with enhanced capabilities to make more accurate and timely decisions.

For further information, contact Nicholas Bertoldo (bertoldo1@llnl.gov) or Paris Althouse (althouse3@llnl.gov).

Meteorological Measurement Capabilities

The Terrestrial and Atmospheric Monitoring and Modeling (TAMM) group operates two meteorological towers. A 40-m tower is located at the Livermore Site, and an 8-m tower is at Site 300. Data from the towers are used:

- As input for regulatory purposes and emergency-response atmospheric dispersion models.
- To support environmental field activities.
- As information potentially related to the health and safety of workers.
- To monitor typical climate and extreme weather events.
- To support other LLNL activities.

In November 2003, we modernized the tower network by adding and improving instrumentation as well as installing new data loggers. Data are now downloaded via modem onto personal computers (PCs) at two locations. This approach allows redundancy in that data are now transmitted to and can be accessed every 15 minutes by the Environmental Protection Department server, and data are also displayed on the LLNL Weather Pages, which can be found at the following internet address: http://www-metdat.llnl.gov/. We plan to expand and revise the database formats to allow display, plotting, and downloading of all measured variables and derived parameters.

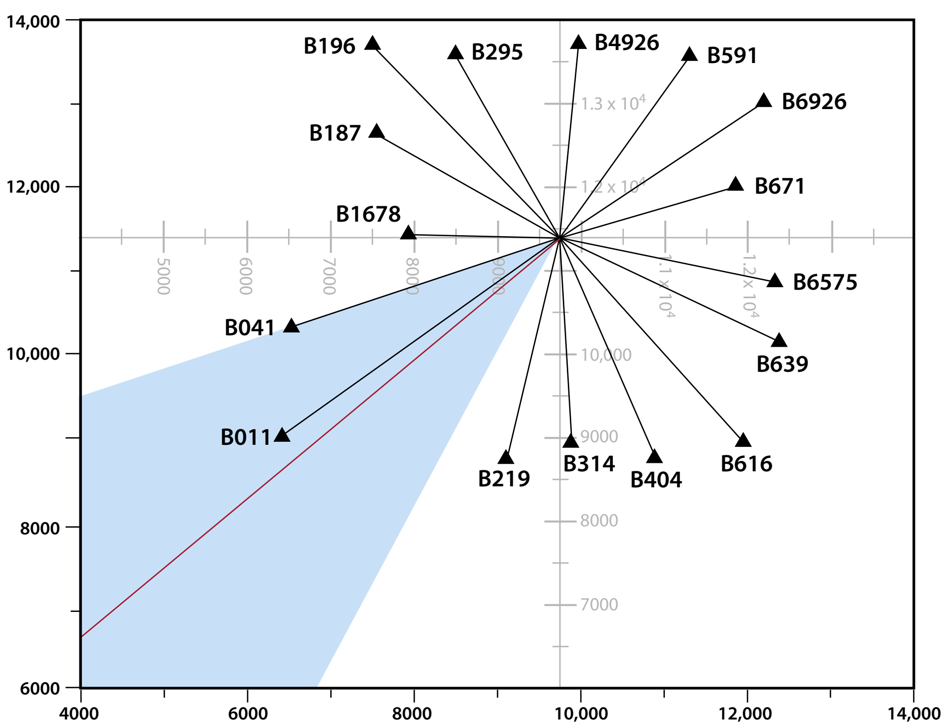


Figure 27. RTRAM sensor network, with a plume overlay showing an event that would pass the B219 sensor. Data from the B011 sensor are compared to the plume overlay for determining airborne radioactivity. This plot uses the LLNL Northing and Easting coordinate system.

Figure 28. EPD personnel and an independent auditor are shown at Livermore's 40-m meteorological tower during the initial audit of new instrumentation.

New instruments installed at the 40-m tower (Fig. 28) include vertical wind sensors at the 10- and 40-m levels, a 3D sonic anemometer at the 10-m level, a barometer, an additional relative humidity sensor at the 10-m level, a net radiometer, and ground thermometer and flux plates. Vertical wind sensors estimate the vertical turbulence, which is important input to dispersion models. The 3D sonic anemometer will provide more accurate horizontal and vertical turbulence values during the frequent light-wind conditions at LLNL. This instrument will be tested for long-term use instead of the mechanical sensors currently in use. A drawback is that the new anemometer requires considerable power and would not be practical during a prolonged power failure. Its performance must also be analyzed during strong winds or heavy rain. The net radiometer has up- and down-facing pyranometers to measure incoming and reflected solar radiation, and up-and down-facing pyrgeometers to measure incoming and ground-emitted infrared radiation. Net radiation can be used to calculate the surface energy balance and vertical stability, which are important for dispersion model inputs and estimating vertical transfers of heat and water vapor. Soil thermometers, flux plates, and a moisture probe are used to estimate the vertical transfer of heat and water vapor from the ground surface. We installed improved temperature sensors at the 2-, 10-, and 40-m levels, allowing more accurate measurement of vertical temperature differences for estimating stability. Finally, data on relative humidity at both the 2- and 10-m levels will allow us to independently estimate evaporation and vertical evaporative heat flux.

We replaced the wind vanes and anemometers at the top of the 8-m tower at Site 300 to obtain more accurate measurements, especially at lower wind speeds. We installed a vertical propeller anemometer at the 8-m level. The existing thermometer was replaced with a more accurate model, and another was installed at the 2-m level to calculate vertical stability. A more accurate relative humidity sensor was installed at the 2-m level. We installed a barometer as well as a pyranometer used to measure incoming solar radiation. Rain gauges continue to monitor rainfall at both sites so that we can estimate runoff for environmental monitoring and stream flow.

Along with our new data loggers at both towers, we installed relatively inexpensive software to download via modem and archive tower data every 15 minutes on two PCs. In the past, a single computer collected data from the towers, and only a few days of data could be stored on and retrieved from the data loggers. Our primary PC is now located in EPD, and another is located at the Hazards Control Department's Operations Support Center. Many months of data can be stored and retrieved by the PCs in case of an interruption in data downloading. The second PC also allows emergency-response officials to directly view the latest meteorological data and most likely direction of transport in case of an unplanned release. We plan to incorporate a meteorology and plume display system recently developed by LLNL's National Atmospheric Release Advisory Center.

Our future plans include preparing a rainfall climatology report for both the Livermore Site and Site 300. This report will be based on manual observations made since 1958 and 15-minute measurements taken since the late 1980s. The report will include monthly and annual normal, medians, and extremes; frequency of various rainfall amounts; and return period of various amounts falling from 15 minutes to annual and seasonal amounts. A more complete climatology is planned once we have an adequate sampling of data from the new measurements.

For further information, contact Brent Bowen (Bowen6@llnl.gov)

Advances in Pollution Prevention at LLNL

Pollution Prevention (P2) efforts at LLNL have been ongoing for more than 15 years. This article summarizes some of our recent and current projects, ranging from use of photovoltaic arrays and "green" building concepts to studies of pilot electric vehicles.

Since 2001, we have teamed with individuals in other LLNL directorates to obtain funding from the DOE's High-Return-On-Investment (ROI) P2 Program. Two such projects were recognized with DOE and EPA awards. The Water Recovery/Drain Down System project was the recipient of a 2002 Federal Energy and Water Management Award, a 2002 DOE Departmental Energy Management Award, and an EPA Green Government Award. This project (Fig. 29a) involved the purchase and conversion of a water-tank trailer to facilitate removal, storage, and replacement of chiller water during maintenance operations. The Photovoltaic Demonstration project (Fig. 29b) involved the installation of three types of photovoltaic arrays at the LLNL Discovery Center to demonstrate different photovoltaic technologies and deployment scenarios. The project received an EPA Green Government award.

During 2002, the EPD and Plant Engineering jointly sponsored a Leadership in Energy and Environmental Design (LEED) training session to help familiarize selected LLNL, Sandia National Laboratories, and Lawrence Berkeley National Laboratory personnel with the concepts underlying green building. The idea of green building emphasizes the design of buildings that are efficient in use of materials, energy, and other natural resources throughout their lifecycle, and it incorporates consideration of human health, the natural environment, and the developed environments of site and community. Costs for well-designed green buildings are comparable to those for conventional buildings, and life cycle costs can be considerably less. To further integrate such concepts into LLNL buildings, we will bring an expert to LLNL to help incorporate green building specifications into plans for several LLNL office buildings scheduled for construction in the near future.

In the spring of 2003, we brought a new P2 web site online for LLNL employees (the address is http://www-epd/p2). The web page is a resource for employees regarding P2, energy efficiency, reuse and recycling of materials, green building, and other environmental topics. Employees can also use the site to suggest P2 ideas, ask questions about P2 planning and implementation, and learn about P2 current events. Pollution prevention questions can also be directed to the Earth Hotline.

Figure 29. (a) The award-winning Water Recovery/Drain Down System uses a water-tank trailer to facilitate removal, storage, and replacement of chiller water during maintenance operations. (b) Photovoltaic arrays are located at the LLNL Discovery Center. (c) Energy-efficient electric vehicles are now being integrated into the LLNL fleet.

At part of our Vehicle Wash Water Recycling System, we installed a wash water reclamation system at the LLNL Fleet Maintenance vehicle wash facility. This system conserves water, reduces the quantity of chemicals used for cleaning, and improves the trapping of oils and greases. Finally, the Global Electric Motorcars Pilot project funded the purchase of a limited number of DaimlerChrysler Global Electric Motorcars (GEMs) for a pilot study by the Fleet Management Group. The study, carried out in early 2003, evaluated the integration of electric vehicles (Fig. 29c) into the LLNL fleet. The pilot effort was deemed a success, and LLNL directorates can now work with Fleet Management to purchase GEM cars for continued onsite use.

For further information, contact Katharine Gabor (gabor2@llnl.gov).

Chemical Tracking Inventory System

The Laboratory's chemical inventory system, ChemTrack, continues to develop and expand in response to regulatory and operational requirements. We currently track more than 20,000 different chemical products in approximately 2,600 locations throughout the Livermore Site and Site 300, with new products arriving daily. Various LLNL organizations use ChemTrack as a tool to identify potential chemical safety concerns, ensure that facilities are maintaining inventories consistent with authorized safety limits, provide employees with electronic access to related Material Safety Data Sheets (MSDSs), and report chemical usage and inventory data to local, state, and federal agencies. With cooperation from chemical users and corresponding improvements in data quality, the inventory performance and accuracy of ChemTrack have increased in the past three years.

ChemTrack uses bar codes, laser scanners, and a stable of customized software applications to track hazardous materials among approximately 1,500 diverse users, including custodians, craft and maintenance workers, as well as scientists and engineers. ChemTrack recently deployed portable data assistant (PDA) technology and improved software to scan and update chemical inventories. These devices offer several advantages, including ergonomic improvements, a user-friendly interface, updated software, and increased versatility that will provide for future expansion and capabilities.

In the past year, we completed several design enhancements that will improve our ability to monitor and track chemical inventories within safety limits. Several related enhancements are well along in development, including web-based tools to initiate chemical transfers to new custodians and storage locations, notify recipients of incoming chemicals, and alert facility management to potential inventory overages. In mid-2004, we deployed new software to capture and validate chemical purchase data and streamline bar-coding operations at receiving and distribution points.

ChemTrack continues to improve web-based access by employees and waste management personnel to MSDSs by electronically indexing, scanning, and linking documents to chemicals in the inventory. Currently, most of the approximately 165,000 bar-coded chemical containers in ChemTrack are electronically linked to corresponding MSDSs, with the match rate increasing each month as new products are received.

The ChemTrack staff continues to provide a balance of chemical inventory and regulatory compliance services to the Laboratory, while reinforcing the responsibility and providing the means for individual custodians to properly manage hazardous materials. LLNL has engaged in a wide variety of technical exchanges and collaborative inventory and MSDS initiatives over the past several years with private industry, other DOE sites, and campuses of the University of California. ChemTrack software is currently licensed for use by Clorox Corporation and by the University of California at Davis.

For further information, contact Steve Harris (harris12@llnl.gov).

Protecting Wildlife Resources

Our staff of wildlife biologists is improving the Laboratory's collective knowledge of urban biology at the Livermore Site and continues to make new discoveries at Site 300. We are working closely with the U.S. Fish and Wildlife Service to help recover several threatened and endangered species, and to provide data relevant to recovery efforts. The following highlights demonstrate how such work and new information are helping to protect biodiversity and promote adaptive management while supporting and enhancing programmatic operations.

Efforts to protect the native and threatened California red-legged frog (*Rana aurora draytonii*) began shortly after a problem was detected at the Livermore Site in the winter of 1999. Control measures commenced in 2000 to eradicate the invasive, nonnative, predatory bullfrog (*Rana catesbeiana*) in the 12.5-million-gallon Drainage Retention Basin. Draining the basin to remove bullfrog larvae and nonnative channel catfish (*Ictalurus punctatus*) was successful in that it slowed the progression of bullfrogs into other sensitive aquatic resources. Currently, dewatering manageable aquatic habitats in the fall and winter, weekly egg-mass removal during the breeding season, and other periodic control measures have further slowed the invasion. Biologists are investigating the use of innovative techniques, such as the natural aquatic pest-control chemical Rotenone, to break the breeding cycle, which might facilitate removal of bullfrogs and sustainability of California red-legged frog populations in the basin.

At Site 300, we continue gathering data to enhance our understanding of how operations such as prescribed burns can influence the biological function, ecology, and distribution of species. Our monitoring and research covers a wide array of species ranging from invertebrates, such as fairy shrimp and valley elderberry longhorn beetles (*Desmocerus californicus dimorphus*), to herpetofauna (amphibians and reptiles), birds, and mammals.

In 2002, LLNL biologists began documenting the presence and distribution of coast horned lizards (*Phrynosoma coronatum*) in relation to prescribed burns and microhabitat characteristics. Although further research is needed, coast horned lizards appear to be associated with frequent prescribed burns and are mostly absent from areas without burning. Biologists coordinated with a local herpetologist, the U. S. Fish and Wildlife Service, and LLNL firefighters in 2003 to conduct a prescribed burn within coastal sage scrub habitat at Site 300 to determine the effects of such burning on the Alameda whipsnake (*Masticophis lateralis euryxanthus*) (Fig. 30). Mark-and-recapture data will be compared between pre- and post-fire years to assess impacts to this threatened species.

We initiated a comprehensive Avian Monitoring Program in 2002 to gain insight into the little understood avian diversity of Site 300. The intent was to determine the diversity, abundance, and distribution of avian species at the site. We have used constant-effort mist netting at the Elk Ravine Bird Banding Station; site-wide, variable, circular, plot point counts; and intensive nest searches. Mist netting is an invaluable technique because it allows biologists to determine the health, sex, survivorship, and age of each captured species; to assess migration; and to identify secretive species that may not be detected otherwise. Plot point counts were distributed throughout the site to determine species diversity and distribution. Intensive nest searching was done in 2002–2003 for the loggerhead shrike (*Lanius ludovicianus*), tricolored blackbird (*Agelaius tricolor*) (Fig. 31), and birds of prey. To date, more than 110 avian species have been documented at Site 300.

In terms of plants, eight rare species are known to occur at Site 300. Current restoration and monitoring efforts are focused on four of these species because they are considered endangered throughout their range. The four species are the large-flowered fiddleneck *(Amsinckia grandiflora),* big tarplant *(Blepharizonia plumosa),* California diamond-petaled poppy *(Eschscholzia rhombipetala),* and round-leaved filaree (*Erodium macrophyllum*).

We are working with the U.S. Fish and Wildlife Service and U.S. Bureau of Reclamation on continued monitoring of native and experimental populations of the large-flowered fiddleneck, and to further develop techniques for habitat restoration and maintenance. The effects of prescribed burns on the large-flowered fiddleneck and native perennial grasslands are currently being studied in the Site 300 experimental population. Because the number of plants in all native and experimental populations of this species has been low in recent years, we have conducted rapid seed-bank enhancement of the LLNL experimental population and an experimental population at Black Diamond Mines Regional Park. We planted 6000 seeds in the two populations in the winter of 2002 and an additional 7380 seeds in the winter of 2003.

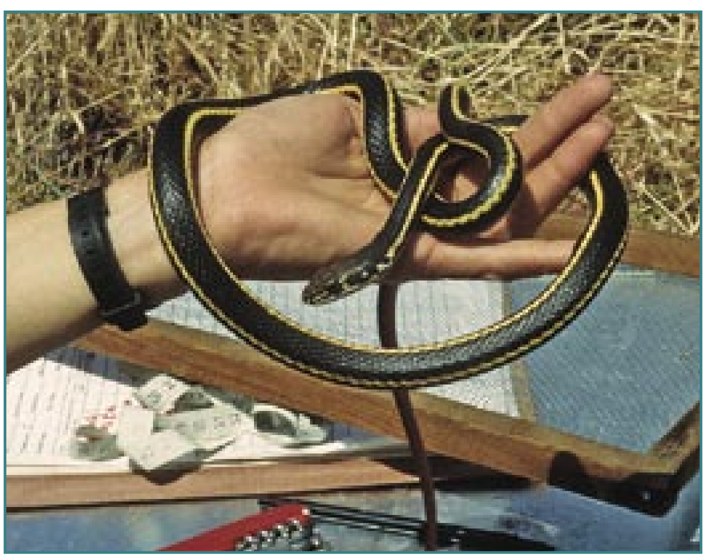


Figure 30. Mark-and-recapature data collection will help determine the effects of Site 300 prescribed burns on the threatened Alameda whipsnake.

Figure 31. Intensive nest searching was done in 2002–2003 for several avian species at Site 300, including the tricolored blackbird.

The big tarplant (Fig. 32) is an extremely rare species, but it is common at Site 300, especially in areas of frequent prescribed burns. This is true despite the fact that the big tarplant does not survive direct contact with late-spring prescribed burns at Site 300. Big tarplant research is currently directed at determining the correlation between prescribed burns and tarplant distribution.

The diamond-petaled poppy (Fig. 33)—discovered at Site 300 in 1997—was considered to be extinct for approximately 50 years when it was rediscovered in California's Carrizo Plain in 1992. The Carrizo Plain and Site 300 populations are the only known locations where the species occurs. The distribution and abundance of the poppy are annually monitored, and research is focused on how environmental factors affect the fecundity of this species.

Figure 32. LLNL biologists are working to establish a statistical correlation between controlled burns and populations of the big tarplant at Site 300.

The round-leaved filaree was discovered at Site 300 during a botanical inventory in 2002. In the two locations where the species occurs at Site 300, it is only found on the berms of annually graded fire trails. Our research will attempt to determine how different management practices, including grading and prescribed burning, affect the abundance of the species.

Finally, outreach efforts have become an integral part of the wildlife program at LLNL. Biologists present conservation-related topics to elementary and middle schools, professional groups, colleagues, and the community. LLNL biologists recently helped a local park agency start a bullfrog-control program for the benefit of declining native amphibians, including identification and ecology training, survey strategies, and control techniques. Working with LLNL's Public Affairs Office, biologists have authored a series of monthly articles entitled *LLNL's Wild Side*, to inform and educate LLNL employees about the rich biodiversity found in the region. Each article has seasonal importance tied to the month it appears and tips on how individuals might see the featured species.

For further information, contact Michael van Hattem (vanhattem1@llnl.gov) or Lisa Paterson (paterson1@llnl.gov).

Figure 33. The diamond-petaled poppy was thought to be extinct until it was discovered at Site 300 in 1997. It's distribution and abundance are monitored annually.

Cross-Directorate Environmental Activities

Introduction

The Environmental Protection Department provides environmental technical support as a partner with organizations or groups within the State of California and elsewhere in the nation. In some cases, EPD personnel lead the efforts; in others, they participate under the leadership of another LLNL organization or outside agency. Supporting national initiatives continues to draw on our expertise in a broad range of fields, from scientific technology to knowledge of regulations.

The technology and research highlights featured in earlier sections of this publication show how Environmental Protection Department activities are being applied to support internal needs at LLNL. Here, we focus on our broader involvements around California, the nation, and the world. We are now responding to urgent needs to provide innovative support to the U.S. Department of Homeland Security (DHS) and the Nuclear Regulatory Commission (NRC).

Key Support to the Nonproliferation, Arms Control, and International Security Directorate

Restoration Domestic Demonstration and Application Program (DDAP)

DDAP is a collaborative project between LLNL and Sandia National Laboratories (SNL) and was funded in FY 2003 by the DHS. The primary objective is to develop procedures, plans, new tools, and technologies that will reduce the time required to restore transportation nodes following a biological attack. Current efforts are focused on a potential release of aerosolized *Bacillus anthracis* spores at an airport, such as San Francisco International Airport (SFO), but the procedures and tools will be transferable to other transportation operations. By conducting in-depth analyses of a limited number of facilities, the project will examine in detail many factors that must be considered during a restoration operation. From facility-specific plans and procedures, a template will be created to simplify development of restoration plans and procedures for other, similar facilities.

The airport DDAP will:

- Specify characterization, decontamination, and verification technologies using SFO as the model airport.
- Demonstrate rapid, high-throughput methods to determine spore viability on samples collected after decontamination.
- Establish collaboration with end users and other stakeholders.

We conducted a detailed survey of SFO in June 2003 to help develop a restoration plan to cover a variety of release scenarios (Fig. 34). Detailed information was obtained on types of surfaces and materials, sensitive equipment, air circulation and flow, and other data necessary for effective decontamination. A draft restoration plan was prepared, and data gaps were identified. We anticipate that the restoration plan will be ready for full-scale demonstration in FY 2005.

Figure 34. The DDAP survey team at San Francisco International Airport (top) focused on many different areas, including HVAC systems (upper, left), boarding areas, and ticket counters of the International Terminal (bottom, left). The Unified Command (bottom, right) participating in the Tabletop Exercise consisted of experts and decision makers from around the country.

Current biodetection technologies were surveyed for their ability to integrate with viability-based methods. Work included protocols for rapid spore germination, optimizing methods for RNA extraction from surrogate microorganisms for nucleic-acid-based viability determinations, identifying potential RNA targets for reverse transcription PCR, developing a protocol for integration with real-time PCR for detection, and designing experiments to evaluate combined nucleic-acid-based methods and dual-label methods targeting germinated spores of *B. thuringiensis* (which is a surrogate for *B. anthracis*).

"How clean is safe?" remains one of the most important issues associated with decontamination and restoration. Work by the National Academy of Science (NAS) on this topic was initiated in 2003, the scope for the study was completed, and an expert 18-member committee was appointed. Members have expertise in anthrax, epidemiology, microbiology, veterinary medicine, aerobiology, bioweapons detection, exposure assessment, risk assessment, risk communication, sociology, and transit and transport safety. The NAS study began during the first quarter of FY 2004. Within 18 months, the committee will evaluate the data available to set safe cleanup levels, and options for those levels, for anthrax and potentially for smallpox and plague as well.

A Restoration Workshop held at LLNL in September 2003 provided a forum for discussing the Concept of Operations—including command structure, roles, functions, and procedures—for decontaminating and restoring a major transportation facility following release of a biological warfare agent. Participants included decision-makers from many federal, state, and county agencies involved in the response and planning processes following actual terrorist events, along with subject-matter experts in the field of biodefense. The workshop identified three areas to decrease restoration time: (1) pre-planning and a pre-event restoration plan, (2) better sample collection and analysis, and (3) improvements in fumigation technologies. The upcoming large-scale demonstration will incorporate one or several of these areas.

In April 2004, a two-day Biological Restoration Tabletop Exercise was held at the SFO Emergency Operations Center. The main objectives were to test the effectiveness and completeness of our restoration templates, and to verify our Concept of Operations structure for a large-scale biological attack on a major transportation facility. The proceedings from the exercise, distributed to participants in August 2004, summarize the major issues and lessons learned that emerged from the exercise, including key time-savers for restoration following a biological attack.

For further information, contact Ellen Raber (Raber1@llnl.gov).

Gaseous Reagents for Building Decontamination

The restoration of buildings contaminated during the anthrax letter attacks of 2001 revealed a national need for decontaminating large, enclosed and semi-enclosed structures. In 2002, Environmental Restoration Division researchers won a competitive grant from the DOE's (later the Department of Homeland Security's) Chemical Biological National Security Program to study the use of gaseous reagents to restore buildings contaminated with biological agents. The objectives are to determine how gaseous reagents can be used to restore contaminated ductwork, and if ductwork can be used to deliver gaseous reagents to attached, contaminated rooms and office spaces.

To date, our work has focused on the use of hydrogen peroxide vapor (HPV) as a gaseous reagent because HPV ultimately decomposes into water and oxygen, which are benign. The bulk of work focuses on room-scale experiments to determine the HPV concentrations and spore kills resulting from various methods of introducing HPV into a room or ductwork. Experiments are done in a trailer (Fig. 35a) equipped with a model heating, ventilation, and cooling system; a near-infrared (near-IR) detection system for measuring HPV concentrations at six different locations within the test room or ductwork; a vapor generator; and a computer-controlled system for collecting data

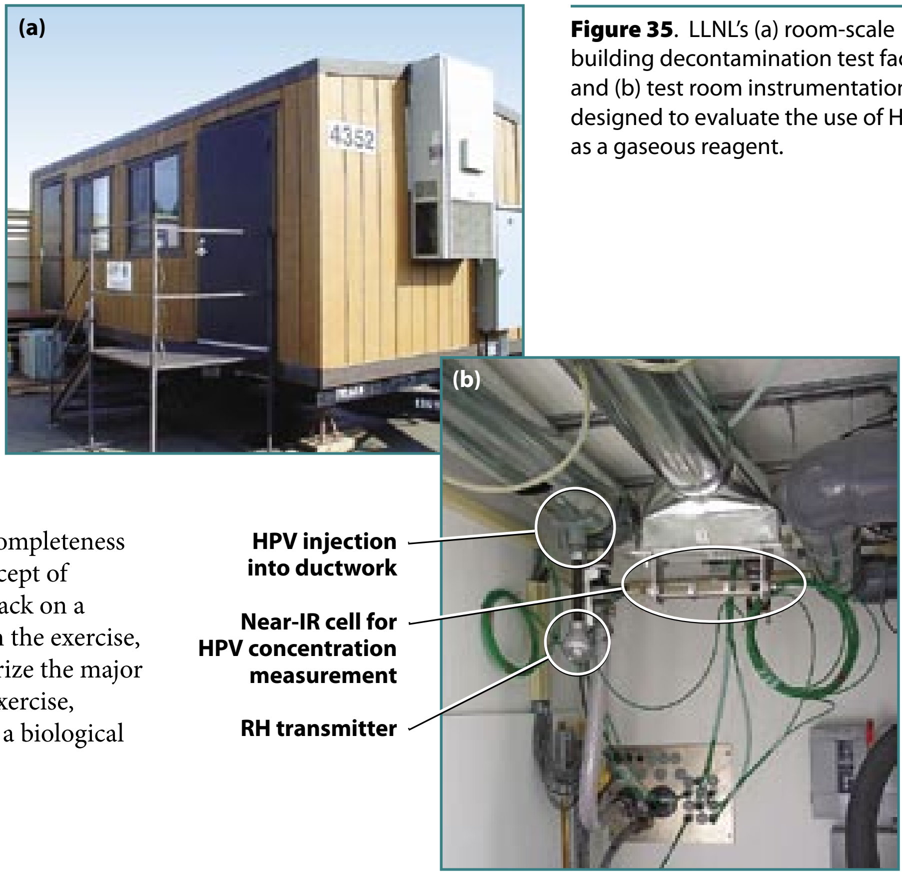


Figure 35. LLNL's (a) room-scale building decontamination test facility and (b) test room instrumentation are designed to evaluate the use of HPV as a gaseous reagent.

on temperature, flow, and relative humidity (Fig. 35b). Results to date indicate that galvanized steel, a common material for ventilation ductwork, may catalyze the decomposition of HPV. As shown in Fig. 36a, the concentration of HPV injected into approximately 85 ft of 6-inch galvanized ductwork decreased by almost 50%. Future experiments will investigate the decomposition of HPV in ductwork made of other materials. Preliminary data generated by this project was used by the EPA to remediate one of the buildings contaminated during the 2001 anthrax letter attacks.

To better understand the decomposition of HPV within galvanized steel ductwork, we are modeling experimental results with computational fluid dynamics. This portion of work is being performed by the Indoor Environment Group at Lawrence Berkeley National Laboratory, which is a collaborator in the project. A preliminary model has been constructed for a 30-ft section of ductwork, which includes decomposition of HPV at the interior surface of the ductwork (Fig. 36b). The model has been verified by comparison with the results from an analytical model, and it is currently being expanded to approximately 85 ft. so that we can model the results shown in Fig. 36a. Modeling results will be important in developing decontamination strategies for larger and more complicated ventilation systems.

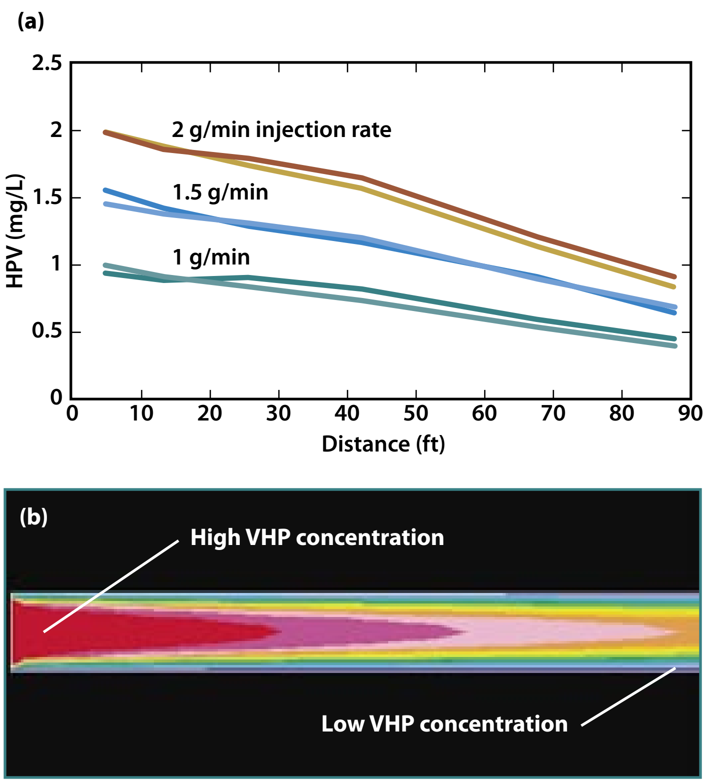


Figure 36. Our preliminary results are showing that (a) galvanized steel ductwork consumes HPV. (b) Preliminary computational fluid dynamics modeling is used to increase our understanding of the reaction of HPV with ductwork.

To begin scaling up the process to systems larger than our current experimental setup, we developed a survey to obtain information on architectural and ventilation system features from real buildings—focusing on those features that will most likely impact the use of gaseous reagents for building decontamination. We will combine the information we obtained with results from the room-scale experiments to develop engineering plans for restoring specific buildings. The survey was developed in consultation with a commercial engineering firm specializing in HVAC systems, and it has been tested on three buildings.

An integral part of our project is collaboration with commercial partners. Currently, we have a commercial partnership with Strategic Technology Enterprises, Inc. (STE), a subsidiary of STERIS Corp., an industry leader in the use of HPV as a sterilant in medical and pharmaceutical industries. Collaborations with commercial partners are important because they facilitate the transfer of knowledge gained from room-scale experiments performed at LLNL into practice by the vendors likely to perform future, building-scale restorations. STE has provided an HPV generator and technical support as their contribution to the project.

For further information, contact Matthew Verce (verce1@llnl.gov).

Bioaerosolization and Spore Transport in HVAC Systems

Despite the rapid evolution of decontamination technologies for use against biological warfare agents, important questions remain concerning the dispersion, deposition, and reaerosolization of weaponized spores in HVAC ducts. To help fill this gap in information, we have conducted experiments with aerosolized, fluidized spores in a test apparatus to delineate the extent of spore contamination and deposition behavior under normal airflow conditions within a ventilation duct system. The surrogate biological warfare agent we used in the experiments was the spore-forming bacterium *Bacillus atropheus.* We evaluated three common duct materials: flexible plastic, galvanized steel, and internally insulated fiberglass (Fig. 37a).

Our results show that the efficiency of spore aerosol transmission varied, and the deposition of surrogate biological warfare agent was significantly different in the three duct materials evaluated (Fig. 37b). Deposition velocities were greater than those previously published using latex spheres or fluorescent particles of sulfur hexafluoride (SF_6). After data were normalized to factor out the variability of the spore-dissemination device and thereby eliminate skewing of surface counts, the flexible plastic duct showed about a 10-fold increase in surface spore counts compared to counts for galvanized steel and fiberglass ducts. This finding implies that building contamination would likely vary in the event of a terrorist attack involving anthrax spores, depending on the specific type of duct material used throughout an affected area. Electrostatic charge, internal surface roughness, and internal surface macrostructure roughness were important influences on spore deposition in the three duct materials tested.

The finding that spore transport efficiencies are less than previously estimated, and that deposition of our surrogate biological warfare agent onto duct surfaces is greater than that of nonbiological spheres on steel and internally insulated fiberglass, may aid in calibrating existing particle-transport models. The major effect that static charges had on spore deposition onto plastic duct—more than a 10-fold increase in deposition velocity—may help with transport models and remediation

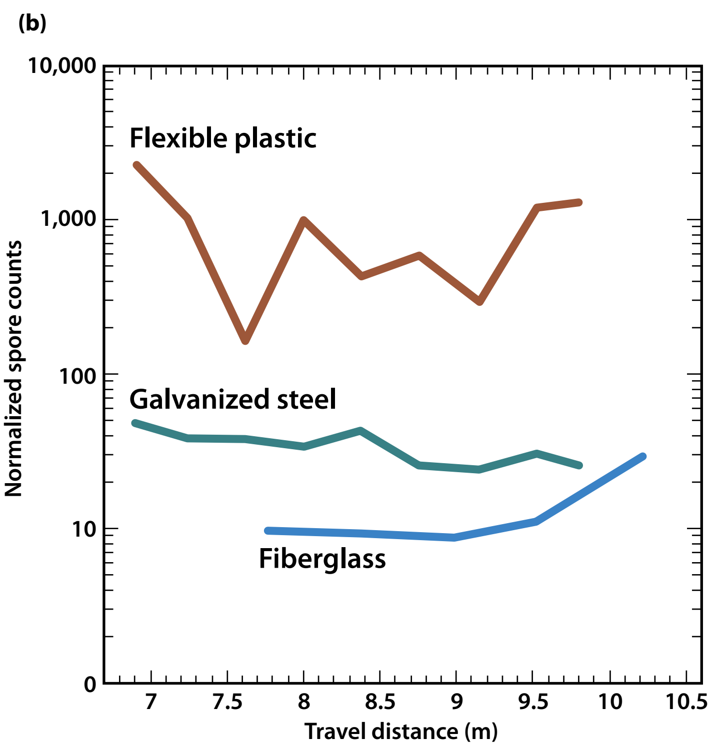


Figure 37. (a) Test system for aerosolization and reaerosolization. (b) Our data suggest that building contamination will vary, depending on the type of duct used throughout an affected area.

activities. We will next address the issue of reaerosolization of spores in ventilation systems.

For further information, contact Paula Krauter (krauter2@llnl.gov).

Strategies for Rail Transit Facility Decontamination

A weapon of mass destruction (WMD) refers to specific chemical warfare, biological warfare, or radiological agents capable of mass casualties. In new work funded by the U.S. Department of Transportation's Federal Transit Authority, and involving all three divisions of the EPD, we will compile a document for decision makers that identifies the major issues surrounding the decontamination of rail-transit facilities and equipment following a terrorist attack involving WMDs and possible strategies for decontamination. The Bay Area Rapid Transit (BART) system will serve as an example facility in this analysis. The strategy options will be based on an analysis of issues in five areas: (1) key technical issues relevant to WMD decontamination, (2) the state of the art in the technology, (3) logistics of implementing decontamination, (4) lessons learned from large-scale decontamination applicable to transit, and (5) roles and responsibilities of lead national agencies. The product of our effort will be a decision-making tool or document that delineates the issues together with recommendations for the most appropriate strategy options.

For further information, contact Tina Carlsen (carlsen1@llnl.gov).

Vulnerability and Risk Assessment

The events of September 11, 2001 reinforced the need to identify critical assets of the nation's infrastructure and assess their vulnerabilities to malicious attacks. A Vulnerability and Risk Assessment Program (VRAP) is one mechanism to help fill the need, with the goal of preventing further attacks or mitigating their impacts. The DHS has made VRAP an important part of its agenda, and other federal, state, and local agencies have begun assessments of their own infrastructures.

The technical, management, and organizational skills of experts within the Environmental Protection Department are now playing an important role in the VRAP effort. In collaboration with experts from other LLNL directorates, we have participated in and managed vulnerability assessment and risk evaluation of dams, reservoirs, water conveyance systems, treatment and distribution systems, and emergency response of combined police, fire, medical, and communications systems.

For further information, contact Richard J. Woodward (woodward5@llnl.gov).

Key Support to the Energy and Environment Directorate

Nuclear Regulatory Commission

Since the spring of 2000, we have had the main responsibility for the Energy and Environment (E&E) Directorate to provide technical assistance to the Nuclear Regulatory Commission (NRC) staff as it responds to requests for renewal of operating licenses from U.S. nuclear power plant operators. The Atomic Energy Act and NRC regulations limit commercial power reactor licenses to an initial 40-year period. Such licenses may be renewed upon successful application to the NRC after 20 years of operation. The operating licenses for more than 100 U.S. nuclear power plants will begin to expire in the year 2006. The review of license renewal applications considers the potential environmental impacts of operating the plants for an additional 20 to 40 years. As a result, the NRC must prepare extensive environmental review documentation under the National Environmental Policy Act (NEPA) to support its decisions.

LLNL has more than 18 years of expertise in providing support for NEPA review documentation to the DOE. Thus, the NRC contracted with LLNL through at least the year 2005 to provide more than $3.7 million of similar technical assistance to its staff. LLNL will assist in preparing the Environmental Impact Statement (EIS)-level NEPA reviews needed to support the Commission's process of license renewal review. To implement its support, our staff leads a team of experienced LLNL staff members selected from the Laboratory. Tasks requested by the NRC include:

- Participating in the review of extensive environmental reports submitted by operators of eight nuclear reactor plants since 2001 as part of their license renewal applications (Fig. 38). More reviews will be accomplished through at least 2005.

- Participating in NRC staff planning meetings, meetings with applicants, and reactor site audit visits; attending public scoping meetings; and making presentations to the public at document review meetings.

- Preparing and reviewing Supplemental EISs needed to support license renewal decisions by the NRC.

- Continuing development of Team Leaders from within the LLNL and EPD staff who will manage and lead several teams consisting of members of four DOE national laboratories. Functions include organizing, executing, and managing the NEPA-related technical support to the NRC staff. The first three LLNL Team Leaders have been assigned to manage the preparation of five Supplemental EISs.

- Providing LLNL staff expertise to the NRC staff and Commissioners in such NEPA-related areas as cultural resource protection, aquatic and upland ecology, water and air quality, wetland protection and floodplain management, radiological waste storage, socioeconomic impact analysis, environmental justice, and Endangered Species Act consultation.

Our staff also assists in proposal preparation for LLNL support to other elements of the NRC and has supported a separate task, within the NRC contract, to the Fission Energy and Systems Safety Program at LLNL. The focus of support is to assist in maintaining and updating an existing Geographical, Environmental, and Siting Information System used by the NRC to review reactor siting and environmental background conditions.

For further information, contact Bruce McDowell (mcdowell5@llnl.gov).

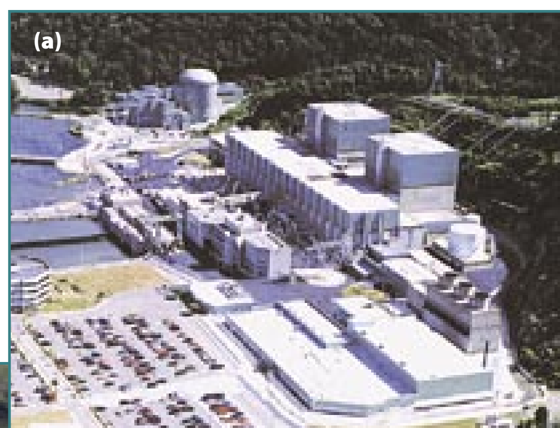


Figure 38. LLNL has assisted in reviewing environmental reports and preparing required documentation for the (a) Peach Bottom Atomic Power Station, (b) Fort Calhoun Nuclear Station, and (c) Point Beach Nuclear Plant, among others, to support license renewal.

Water Contaminant Information Tool

The EPA's Water Protection Task Force has identified the need for an information tool to assist the water utility community in planning for, responding to, and recovering from intentional contamination events. LLNL began work on the Water Contaminant Information Tool (WCIT) after signing an interagency agreement with the EPA. With funding through LLNL's Energy and Environment Directorate, a cross-directorate collaboration was formed involving individuals from the EPD, Energy and Environment, Chemistry and Materials Science, and Innovative Business and Information Services. As a planning tool, the WCIT can be used to support vulnerability assessments, emergency response plans, and the development of site-specific response guidelines. As a response tool, it provides real-time information about specific water contaminants to make decisions about appropriate actions.

The WCIT incorporates a subset of representative chemical, radionuclide, and biological agents. The principal data categories are toxicity and public health, agent properties, sampling and analysis, contaminant behavior and treatment in water systems, availability, and environmental impacts. Utility personnel can calculate the volume of contaminated water and mass of agent required to reach lethal dose levels for 50% of the population (LD_{50}) with various inputs for all agents. Fact sheets can be generated for both the media and water utility personnel. The WCIT supports queries by threat category, aesthetic characteristics, detection methods, treatment process, toxicity levels, and agent properties. A completed database that demonstrates the required functionality was delivered to the EPA in December 2003.

For further information, contact Carol Stoker (stoker1@llnl.gov).

Key Support to The Biology and Biotechnology Research Program

Biotechnology and Environmental Microbiology

Some bacteria have the unique ability to derive energy from the reduction or oxidation of metals. Such capability is relevant to the bioremediation of metal- and radionuclide-contaminated aquifers. Oxidation state can be a key determinant of the aqueous solubility and, therefore, mobility in groundwater of some high-priority contaminants, including uranium, at DOE sites. Thus, a proposed method for remediating metal- and radionuclide-contaminated sites is microbially catalyzed, *in situ*, reductive immobilization of elements such as uranium.

In a project initiated in late 2003, ERD scientists are collaborating with scientists in LLNL's Biology and Biotechnology Research Program to study fundamental biochemical pathways that underlie bacterial interactions with certain metals and radionuclides of concern to the DOE. The research is "genome-enabled," which means that the techniques rely on knowledge of the entire genome of a bacterial species of interest. Bacterial genome sequencing was carried out at the DOE's Joint Genome Institute, which is located near LLNL. One of the research approaches we are using is comparative genomics, which is a rigorous comparison of thousands of genes belonging to several bacterial species that are related metabolically or phylogenetically. Another approach is expression microarrays, essentially a high-throughput analysis that can determine which genes in an entire bacterial genome are turned on or off in response to selected environmental stimuli, such as the presence of specific metals. Our fundamental research should contribute to an understanding of interactions between bacteria and certain metals and radionuclides at contaminated DOE sites.

For further information, contact Harry Beller (beller2@llnl.gov) or Staci Kane (kane11@llnl.gov).

International Activities

The EPD provides international support under the umbrella of an agreement between the United States and individual countries or organizations within a country. In general, EPD work in the international arena is conducted under the auspices of federal agency agreements with foreign countries or organizations, and subsequently under another LLNL organization. The EPD is often asked to develop new solutions, to apply old technologies in a unique way to resolve environmental concerns, or to develop documentation essential to resolve an environmental issue. The focus of our support is most often in the area of radiological issues, and it generally involves the fields of modeling, monitoring, waste management, and remediation. Involvement can extend into other fields as well. For several years, EPD personnel have provided support through partnerships with Morocco and the former Soviet Union. Those efforts are continuing, with variations in the scope of projects and types of support we provide.

Environmental Modeling for Radiation Safety

Environmental Modeling for Radiation Safety (EMRAS) is the latest model-validation program organized by the International Atomic Energy Agency (IAEA). Its purpose is to enhance capabilities of member states to model radionuclide transfer in the environment and to assess exposure levels of the public and biota. The program's success will be an important step in helping to ensure an appropriate level of protection from the effects of ionizing radiation associated with releases of radionuclides. Specific EMRAS objectives are to:

- Test the accuracy of model predictions.
- Improve existing models and specify their parameters.
- Provide a forum for exchanging ideas, experience, and information.
- Recommend priorities for future research.

EMRAS, which will run through 2006, held its first meeting in September 2003. The program has six working groups that are addressing issues ranging from the revision of a handbook of environmental-transfer parameters to the movement of nuclides through specific environments. One of the groups, the Tritium Working Group, focuses on the movement of tritium and radiocarbon in the environment.

LLNL is participating in EMRAS just as it did in an earlier IAEA program, called Biosphere Modeling and Assessment, which ran from 1996 through 2001. Throughout LLNL's history, most of the radioactivity released to the atmosphere from routine operations and accidents has been either tritiated water vapor (HTO) or tritiated gas (HT). Most of the radiological dose received by the public has been from inhaling HTO, or ingesting HTO in food or drinking water as well as organically bound tritium (OBT) in food. As a result, we have an ongoing interest in developing and improving models that can accurately assess the contribution of various forms of tritium to dose to the public (see the article, "New Approaches to Environmental Modeling," earlier in this publication).

The Tritium Working Group plans to model nine scenarios—five terrestrial and four aquatic—that include observations against which model predictions can be compared. Of particular interest to the EPD is a steady-state scenario with concentrations of OBT in milk and meat products as endpoints. Never before have animal data been available for testing models. Another scenario relevant to our interests is one in which concentrations of OBT in tree rings and pine needles have been correlated with atmospheric releases from three sources for more than 30 years. One hypothetical scenario addresses multiple pathways after an accidental release of HTO or HT to the atmosphere. The idea is to aid in emergency response by determining which pathways to dose are the most important, by assessing the most efficient ways to limit the consequences of a release, and by determining what to measure and when to measure it.

All the working groups in EMRAS meet in Vienna, Austria, annually in the autumn. In the spring, the working groups meet annually at participants' facilities. In April 2004, LLNL hosted the Tritium Working Group (Fig. 39), consisting of participants from Austria, Canada, France, Germany, Greece, Japan, the Republic of Korea, the Russian Federation, and the United Kingdom, for the 4-day meeting.

For further information, contact Ring Peterson (peterson49@llnl.gov).

Figure 39. Tritium Working Group of EMRAS after a successful workshop hosted by LLNL in April 2004.

Sister Laboratories Program—Morocco

The Nuclear Nonproliferation Treaty (NPT) entered into force in 1970, marking the beginning of a global effort to control the proliferation of nuclear weapons. Today, the NPT continues to be a cornerstone of the worldwide nonproliferation regime. The International Atomic Energy Agency oversees the primary multilateral means of providing assistance in nuclear-related technologies to developing countries through its Technical Cooperation Program. The technologies provided address fundamental developmental needs, such as food and water supplies, health services, and environmental management. The U.S. provides technical cooperation through the DOE Sister Laboratories Program. In the early 1980s, the U.S. launched an initiative to establish cooperative institutional relationships between its own nuclear research laboratories and those in developing nations that have supported the NPT.

Figure 40. An LLNL researcher is shown collecting vegetation samples at the CNESTEN (LLNL's Sister Lab in Morocco) as part of the Research Reactor Center Baseline Characterization.

The DOE currently sponsors a Sister Laboratory Arrangement between LLNL and Morocco. Our collaborative program (Figs. 40 and 41) includes the exchange of scientific and technical information; collaborative projects; short visits by experts to U.S. laboratories or their foreign counterparts; longer-term personnel assignments ranging from one week to six months; exchange of samples, materials, and instruments; training of scientific and technical personnel; and the use of nonclassified facilities, computers, and equipment.

Our objectives are to support Article IV of the NPT; increase understanding of foreign nuclear authorities and activities; establish a direct line of communication between U.S. nuclear specialists and the nuclear research and scientific communities; build trust and communication through long-term technical interactions; enhance the possibility of spin-off collaborations; and facilitate cooperation in the peaceful uses of nuclear energy.

For further information, contact Mo Bissani (bissani1@llnl.gov).

Figure 41. Participants at an expert mission held at the CNESTEN Site in Morocco, July 2002. From left to right: Bryan Bandong (LLNL), Dr. Zenzouni (Technical Cooperation Manager), Paris Althouse (LLNL), Dr. El Mediori (CNESTEN Director General), and Rick Blake (LLNL).

Former Soviet Union and International Science Centers

The International Science and Technology Center (ISTC, Moscow) and the Science and Technology Center in Ukraine (STCU, Kyiv) were established in the 1990s to help minimize the proliferation of weapons of mass destruction. To this end, funding is provided for weapons scientists and engineers in the former Soviet Union (FSU) to conduct nonweapons research. Involvement in environmental research is an important component of their conversion to nonweapons work. The redirected focus of such highly trained and motivated scientists can lead to unique solutions to environmental problems in the FSU and elsewhere.

Staff members from the EPD are supporting nonproliferation and arms control programs administered by the U.S. Department of State. We serve as senior science advisors, technical reviewers, scientific collaborators, and technical auditors for environmental projects being conducted in the FSU under the auspices of the International Science Centers. Our participation gives us the opportunity to evaluate novel environmental technologies while supporting important U.S. nonproliferation goals. The EPD staff recently participated on the organizing committee and, as session chairs and presenters, at an international conference sponsored by the STCU on the topic of ecological health threats (Fig. 42). The objective was to share information on current U.S. research and development efforts that can assist FSU scientists who are dealing with contamination produced by industrial activities and weapons development during the Cold War. A trip into the Chernobyl Exclusion Zone (Fig. 43) as part of the conference provided a better understanding of projects proposed to the STCU in this area. Additional visits to two National Academy of Sciences of Ukraine institutes produced fruitful discussions with Ukrainian scientists regarding their current and future STCU environmental proposals. Our involvement in environmental monitoring, environmental restoration, and waste management projects under the auspices of the International Science Centers also has the potential for direct-leveraged application to EPD missions.

For further information, contact Kris Surano (surano1@llnl.gov).

Figure 42. A delegation of staff members from the EPD participated at the recent international conference on Ecological and Health Threats Associated with Environmental Contamination, held in Kyiv, Ukraine.

Figure 43. Part of the EPD delegation at the Chernobyl Shelter.

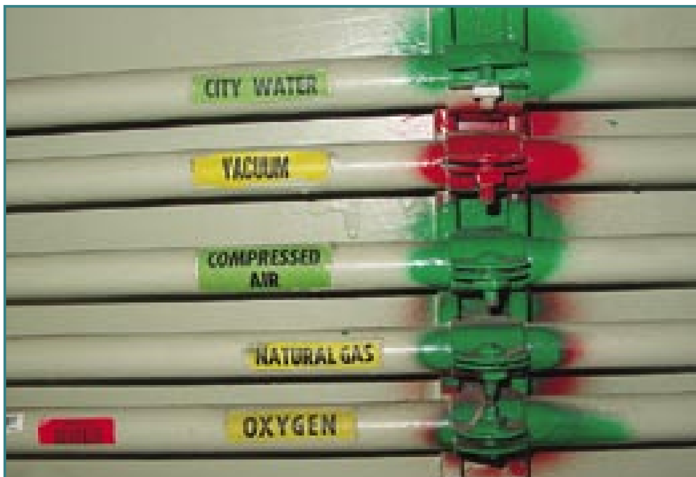
Decommissioning and Demolition of Nuclear Facilities

Strategies for Hazards Identification

As a result of the end of the Cold War, the decommissioning and decontamination (D&D) of surplus nuclear reactors and DOE facilities is taking place nationwide. The National Nuclear Security Administration (NNSA) Headquarters Steering Committee provides guidance to their sponsored D&D process development team. At LLNL, the Disposition Program Manager, who is also a member of the NNSA Headquarters Steering Committee, is responsible for LLNL's institutional D&D activities and projects. An important role is to ensure that LLNL disposition plans support and are consistent with NNSA standards, the Laboratory's Ten-Year Comprehensive Site Plan, and are tactically implemented by the Space Action Team (SAT). At LLNL, the SAT is a multidisciplinary team whose members are drawn from the entire Laboratory.

Since 1998, LLNL has completed more than 51 D&D projects. The D&D initiating process involves preparing a conceptual project plan as well as facility surveillance and maintenance. A project plan includes identifying deliverables and milestones; identifying hazards (Fig. 44) and risk management; establishing controls and a waste deposition strategy; and resource planning, which includes activity sequencing, schedule development, and completion of a cost-loaded schedule. The result of this process is a fully executable project plan. The SAT has received the EPA, Region 9, Champion of Green Government Award for recycling efforts and metrics in performing D&D on contaminated buildings.

For further information, contact Mitch Waterman (waterman1@llnl.gov).



Green: Safe for removal. No issues.
Red: Known hazard. Contact health and safety technician.
Yellow: Caution. Potential hazard. Contact health and safety technician.
Blue: Safe for removal. Requires controlled disposal to municipal landfill.
Black: Used for instructions and editorials.

Figure 44. The identification of hazards is an essential part of our D&D activities. We flag hazards using a highly visible color-coding process. Green paint indicates that materials are safe for removal, and all health and safety concerns are addressed. Yellow denotes caution, and red is applied when a known hazardous material exists. After resolving issues related to the use of yellow or red paint, a SAT health and safety technician applies green or blue paint over the first color to indicate that items are ready for removal.

B251 Risk Reduction Program

Previous activities at LLNL's Heavy Element facility, B251, supported the U.S. nuclear testing program and actinide chemical research programs. The facility was placed in standby mode in the early 1990s. All activities involving the handling of radioactive materials ceased, leaving a legacy of more than 400 inventory items with approximately 900 curies of activity, and 51 gloveboxes containing various levels of contamination. In the early 2000s, it was decided to reduce the risk contained within the facility by removing the inventory of radioactive materials, gloveboxes, and some ventilation systems.

To date, approximately 80% of the total curies of activity have been removed as part of the Inventory Reduction Project and shipped to:

- Other facilities on site for storage or use in other programs.
- Onsite waste management facilities for transfer to the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, or low-level waste disposal facilities.
- The Source Recovery Program at Los Alamos National Laboratory (LANL).

Additional items will be shipped to Oak Ridge National Laboratory for use in the Heavy Element Programs as well as LANL. To date, all 49 gloveboxes and the Blue Cave enclosures in the Glovebox Removal Project have been characterized (Fig. 45). In addition, 14 gloveboxes have undergone decontamination and demolition, and many have been packaged for transfer to the Nevada Test Site as low-level waste.

For further information, contact Brian Anderson (anderson2@llnl.gov).

Figure 45. Example of a B251 Blue Cave glovebox. Following characterization, the equipment and materials stored inside the unit are removed. The next step is to decontaminate and package the glovebox for shipment.

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Environmental Protection Department
Lawrence Livermore National Laboratory
P.O. Box 808, L-626
Livermore, California 94551-0808